Time-Varying Leverage Constraint, Safe Asset Demand and Dollar Exchange Rate

Jingjie Huang*

July 2025

Abstract

I propose a two-country intermediary-based model with financial frictions to study the exchange rate movement and the dynamics of the U.S. external balance sheet. In the model, financial intermedairies are subject to time-varying leverage constraints which limit their ability to raise funds. The key asymmetry in the model is that U.S. Treasury bonds are considered to be safer and offering more liquidity than government bonds issued by foreign countries. Under the symmetric global financial shock, the model is capable to endogenously generate safe asset demand and provide micro-foundation for convenience yield that investors derive from holding US safe assets. In global recessions, the demand for U.S. safe assets increases, convenience yield becomes higher, leading to an appreciation of the dollar. Under the safe asset view, the seigniorage revenues from issuing bond that carry higher convenience yield raise the U.S. consumption share in recessions, despite the U.S. suffering portfolio losses from external positions. The model can also jointly explain the large and persistent CIP deviation due to the tightening of bank regulations after the GFC.

JEL Classification: E44, F31, G12
Keywords: Financial intermedairy, Exchange rate, Safe asset

*Department of Economics, University of North Carolina at Chapel Hill, jht2c@live.unc.edu.

1 Introduction

In the international finance literature, the exchange rate disconnect puzzle is a well-known phenomenon where exchange rates seem to move independently of traditional macroeconomic fundamentals, such as interest rates, inflations, or trade balances.[1] Instead of following the patterns suggested by these economic variables, exchange rates appear to be more closely linked to financial forces. In periods of financial turmoil, it has been shown that exchange rates are more driven by factors such as global risk appetite, financial market safety and liquidity and cross-border capital flows rather than the economic fundamentals that once dominated exchange rate models (Lilley, Maggiori, Neiman, & Schreger, 2022). During the global financial crisis of 2007-2009, investors' risk-bearing capacity sharply declines as uncertainty and financial instability escalate. This heightened aversion to risk triggers a widespread flight to safety, where investors seek assets perceived as secure, such as U.S. Treasuries. As demand for these safe-haven assets increases, the convenience yield on U.S. Treasury rises. This surge in convenience yield signals a stronger preference for U.S. safe assets, which in turn drives up the demand for U.S. dollars, leading to the appreciation of the dollar.

Dollar exchange rate movement has been associated with cross-boarder capital flows and with the "exorbitant privilege" of the U.S. In the global financial system, the U.S. plays a special role as the "banker of the world", who holds risky assets of foreign countries and supplies safe liabilities to foreign investors. Under the risk-based insurance provision view (Gourinchas & Rey, 2022), through these cross-border asset positions, the U.S. earns a risk premium in normal times as a compensation for taking on more risks, and bears losses in global recessions as the insurance pays off. While this view provides important insights, it faces a "reserve currency paradox" (Maggiori, 2017). As insurance payment transfer from the U.S. to the rest of the world during global recessions, the foreigners become relatively wealthier. With the home bias in consumption demand, this would raise the price of the foreign goods and strengthen the foreign exchange rate. However, in

[1] See, (Meese & Rogoff, 1983); (Obstfeld & Rogoff, 1995); (Engel & West, 2005).

the data, we observe that dollar exchange rate always appreciates during global recessions.

In this paper, I propose an open economy intermediary-based model extending (Gertler & Karadi, 2011) that can jointly explain the important features of the global financial crisis. In each country, households consume and save by putting deposits in financial intermediary located in their own country. Governments issue debt and make transfer to households. The core concept of the framework is that the financial interemdairies which facilitate the flow of funds from households to the real economy, face leverage constraints that limit their ability to raise funds. The leverage constraint requires that the market value of an intermedairy must be greater than or equal to a fraction of its risky assets. My contribution to this framework is that I let the fraction in the leverage constraint to be time-varying and depend on how much safe assets financial interemdairies have in their portfolio. If the financial intermediary holds a larger amount of safe assets, his ability to raise funds from the households becomes higher.

A key asymmetry in the model to generate the important asset pricing implications is that all financial intermediaries consider U.S. Treasuries as an asset that is safer and offering more liquidity than other governement bonds issued by foreign countries. A substantial body of research has demonstrated that the U.S. serves as the world's primary supplier of safe assets, a role that has become even more pronounced since the 2008 Financial Crisis.[2] When there is a global financial shock, the international financial system breaks down. Global financial intermediaries become financially tightened and eager to seek liquidity. This leads all financial intermedairies rush to U.S. Treasuries and pay a premium to hold US safe asset because it relaxes their financial constraints. Therefore, given financial intermedairies face deleverage pressure during crisis, the model could endogenously generate safe asset demand and a high "convenience yield" for the U.S. Treasury, causing a dollar appreciation. The model is capable to provide micro-foundation of the convenience yield through the lens of intermedairy-based model with financial friction and also to generate a persistent deviation from uncovered interest parity (UIP) due to the time varying convenience yield.

[2]See, (Gourinchas & Rey, 2007a);(Maggiori, Neiman, & Schreger, 2020)

To study the dynamics during the Global Financial Crisis, I hit the model with a global financial shock that simultaneously tightens the leverage constraints of all the financial intermediaries, forcing them to de-lever as well as adjust their investment portfolio across asset classes. As foreign intermediaries values the liquidity and safety of U.S. Treasury more than the U.S. intermediaries, the foreign intermediaries end up holding more U.S. safe assets and U.S. imtermediaries hold more foreign government bonds. The bond flow is consistent with "flight to safety" during the Global Financial Crisis. The model is also capable to reproduce the positive correlation between bond-flows and exchange rate (Lilley et al., 2022). As more funds flow from the foreign country into the U.S. than the other way around, we obtain a positive net bond flow to the U.S. Hence, the global financial shock which endegenously generate safe asset demand produces a positive correlation between the dollar exchange rate and the net bond flow. Intuitively, given the U.S. safe-haven status, we would expect bond flows into the U.S. during global stress periods as foreign investors seek safety and liquidity, and dollar appreciates due to high convenience yield. During normal times, when investors have a greater capacity to bear risk, capital flows out of the U.S., leading to a depreciation of the dollar.

The safe asset view also has the potential to shed light on understanding U.S. exorbitant privilege during the Global Financial Crisis. The model is capable of accounting for the fact that while the U.S. is a net international debtor with the NFA keeps deteriorating, its net investment income is positive, a noted feature of the U.S. external balance sheet during the GFC. The U.S. takes a long position on foreign risky assets and a short position on dollar bonds. In a "flight to safety" episode, the dollar appreciates and the valuation effects lead to the U.S. suffer a loss on its external portfolio and its NFA declines as we observe in the data. However, the demand for U.S. safe assets allows the U.S. to fund its liabilities at lower interest rates, which generates a seigniorage revenue to the U.S. Higher seigniorage revenue from issuing safe assets offsets losses on holding equities, potentially resulting in a positive net investment income for the U.S. As a result, the countercyclical seigniorage revenue allows the U.S. to consume relatively more than the rest of the world during financial crisis despite the loss on its external portfolio. Thus, the goods market clearing is also consistent with a stronger dollar. On the contrary, under the insurance-provision view, global recessions reduce the U.S. consumption shares since the U.S. suffers portfolio loss and there is a wealth transfer from the U.S. to the rest of the world. Given the home bias in consumption demand, U.S. dollar should depreciate in bad times, which contradicts to what we observe in the data. Under the safe asset view, the U.S. can continue running trade deficits despite having a negative net foreign asset position. Therefore, while the U.S. still suffers portfolio losses from its external asset positions due to valuation effects, it does not necessarily have exorbitant duty and transfer wealth to the rest of the world during the GFC.

I also consider the effects of the endowment shocks in my framework. A negative endowment shock reduces the output of the equity and lowers the return and the price of the equity. Hence, it reduces the profitability of the financial intermediary, which shrinks the net worth of the financial intermedairies. This leads to a contraction of the economy and further impairs the intermediaries' balance sheets. As in the literature on the "financial accelerator" (e.g., (Gertler & Karadi, 2011)), the financial squeeze resulting from a negative endowment shock reduces investment and exacerbates the effect of the original drop in endowment of the output. Thus, a negative endowment shock endogenously tightens the leverage constraint. From the impluse response analysis, we can observe that it generates similar effects but with smaller magnitudes as that from the global financial shock. Additionally, second-order moment matching shows that the model with only endowment shock is not capable to generate large enough standard deviations and other comovements close to the data.

Deviations from the CIP and its dynamics have attracted considerable attention in recent years. The model can be extended to account for the large and persistent CIP deviations during the Global Financial Crisis. The tightened bank regulations after the global financial crisis constrain the financial intermediaries from engaging in arbitrage in the foreign exchange swap market and produce deviations from the CIP. Before the financial crisis, FX swap is considered to be risk-free and there is no constraint on it. After the global financial crisis, under the new Basel III regulatory framework, intermedairies are required to hold a certain amount of equity capital against all assets regardless of their riskiness. By carefully calibrating the parameter that determines the relative tightness of the constraint on FX swaps within the augmented leverage constraint, the model can successfully replicate the CIP deviations observed in the data.

In summary, this paper provides a safe asset view for understanding exchange rate movements, convenience yield, capital flows and the U.S. external balance sheet. The financial intermedairy-based model with time varying leverage constraint offers a novel way of understanding the deviation of UIP, deviation of CIP and U.S.'s special role in the international financial system. The model is able to reproduce the important stylized facts from the data and complements the insurance-provision that emphasizes the U.S. role as the global insurance provider.

Related Literature

The paper contributes to the active research that uses fluctuation of "convenience yield" of safe assets to explain exchange rate movements or deviations from uncovered interest parity. Several recent empirical papers include (Jiang, Krishnamurthy, & Lustig, 2021), (Koijen & Yogo, 2020) and (Engel & Wu, 2023) suggesting convenience yield drives exchange rate. (Jiang et al., 2021) assume an exogenous convenience yield derived by foreign investors from holding U.S. safe assets during times of global stress that generates a deviation from uncovered interest parity and dollar appreciation. Fluctuations on the safe asset demand can explain the convenience yield, as in (Krishnamurthy & Vissing-Jorgensen, 2012) and (Krishnamurthy & Lustig, 2019). On the theoretical side, (Kekre & Lenel, 2024) present a model of convenience yield and risk premia in a general equilibrium model of the global economy. They use a bond in utility function with a preference shock representing an exogenous foreign safe asset demand shock to derive convenience yield and explain exchange rate and asset prices. (Engel, 2016) investgates the forward premium puzzle and the persistent appreciation of high-interest-rate currencies suggesting that liquidity demand could jointly explain the empirical regularities. (Valchev, 2020) introduces a consumption trade cost depending on the safe assets that provide explanation of the uncovered interest parity puzzle across different time horizons through bond convenience yields. These papers provide evidence that deviations from UIP may be attributable in part to liquidity or convenience yields, and that this return to liquidity also influences the level of the exchange rate. However, models in previous literature take deviation from UIP due to convenience yield either as exogenous, or bonds are in utility function, or from exogenouly given bond demand functions. In comparison, this paper contributes to the literature by introducing an endogenous mechanism that a global financial shock which tightening the leverage constraints of the financial intermediaries triggers a rise in the safe asset demand and the convenience yield.

The paper closely relates to research that focuses on the role of limited risk-bearing capacity of the financial intermediation in explaining exchange rate and capital flows. Following the pioneering work of (Gabaix & Maggiori, 2015), many studies show that intermediary frictions matter to exchange rates and financial stability. (Maggiori, 2017) shows that limited risk-bearing capacity among financial intermediaries leads to exchange rate movements in response to capital flows. More recent work by (Itskhoki & Mukhin, 2021) incorporate asset demand shocks in partially segmented financial markets to explain exchange rate puzzles. (Fang & Liu, 2021) build a quantitative model to resolve the exchange rate puzzles by analyzing the interaction between financial intermediary leverage constraints and volatility. However, the limitation of their model is the simplifying assumption that intermediaries only live for two periods. Instead, the critical feature of the model in this paper is the presence of long-lived financial intermedairies that face leverage constraints. The theoretical framework of this paper takes the general idea from the classical literature of financial friction and financial accelerator of the intermediaries. It closely follows the model framework from (Gertler & Karadi, 2011). I find out that the framework can be extended into a two country model which can jointly explain exchange rate movements and U.S. external balance sheet during and post global financial crisis periods. The closest paper is (Devereux, Engel, & Wu, 2023) in which the model assumes that U.S. government bond which receives the lowest constraint due to it's advantage as a superior collateral asset on intermediary's balance sheet. A key distinction in my paper's model is the inclusion of the role of safe asset as the core part of the accelerator which is time-varying. Holding more safe assets can relax the financial constraint and enhance the ability to raise funds from households. The model is capable of generating large asset price movements as in (He & Krishnamurthy, 2013).

The paper also relates to vast amount of research studying the special role of the U.S. in the international financial system (Mendoza, Quadrini, & Rios-Rull, 2009), (Gourinchas, Rey, & Truempler, 2012). A large amount of empirical work have documented that U.S. has a special external balance sheet. (Gourinchas & Rey, 2007b) analyze the composition of the US external positions and emphasis the importance of excess returns in the global financial adjustment process. (Mendoza et al., 2009) and (Caballero, Farhi, & Gourinchas, 2008) build models to account for this global pattern of portfolio returns. (Maggiori, 2017) and (Gourinchas & Rey, 2022) argue that U.S. enjoys "exorbitant privilege" during normal times and experiences"exorbitant duty" during global financial crisis periods. This paper analyzes U.S. exorbitant privilege through the lens of safe assets and argues that higher seigniorage revenue potentially allows the U.S. to generate positive investment income and consume relatively more despite the loss on its external portfolio. In other words, U.S. does not necessarily have exorbitant duty during times of global stress as mentioned in (Jiang, 2024). The main contribution of this paper is to characterize the U.S. balance sheet under the same general equilibrium model and provide implications for the relationships between exchange rate and net foreign asset positions, net investment income and bond flows.

The U.S. dollar has long served as the global reserve currency and the primary currency for issuing global safe assets. (Ivashina, Scharfstein, & Stein, 2015) demonstrate that non-U.S. banks are also heavily involved in dollar-denominated activities. (Maggiori et al., 2020) confirm this finding and additionally highlight that the dollar's dominance increased following the financial crisis. (Du, Im, & Schreger, 2018) and (Krishnamurthy & Lustig, 2019) emphasize the role of US treasury securities as safe assets in the international financial system. This paper complements the existing literature by proposing a general equilibrium model and explain the dynamics of dollar exchange rate and U.S. external balance sheet through the global safe asset's view.

Deviations from the covered interest parity after the GFC and its dynamics have attracted considerable attention in recent years: (Du, Tepper, & Verdelhan, 2018) and (Avdjiev, Du, Koch, & Shin, 2019). The literature has proposed different explanations and evidence of deviations of CIP, such as bank regulation change (Cenedese, Della Corte, & Wang, 2021); imbalances in the demand for and supply of FX hedges (Borio, Iqbal, McCauley, McGuire, & Sushko, 2018); segmented money markets (Rime, Schrimpf, & Syrstad, 2022); and reserve accumulations by central banks at the zero lower bound (Amador, Bianchi, Bocola, & Perri, 2020). This paper does not provide a new explanation for deviations of CIP. Instead, following the perspectives of (Cenedese et al., 2021) that tightened bank regulations after the global financial crisis constrain the intermediaries from engaging in abitrage in foreign exchange swap market that leads to deviations of CIP. In this paper, I study deviations of CIP, the dynamics of exchange rate and US external balance sheet within a unified quantitative model.

The remainder of this paper is structured as follows. Section 2 shows the stylized facts that motivate my model. Section 3 describes the model framework. In section 4, I calibrate the model to the data and study the model's impluse responses to a global financial shock and a global endowment shock and study the dynamics of U.S. external balance sheet. In section 5, I extend the model to include FX swap contract and explain the deviations from CIP. Section 6 concludes the paper.

2 Motivating Facts

In this section, I present some stylized facts around time of the global financial crisis that helps to motivate the model.

Fact 1: The dollar exchange rate strongly comoves with global risk appetite during the Financial Crisis.

It is well known that the dollar exchange rate is disconnect between macroeconomic fundamentals, such as the interest rate differential, inflation differential and trade balances. Instead, it exhibites a stronger correlation with global risk appetite during the Financial Crisis (Lilley et al., 2022)[3]. As foreign investors seek safe-haven assets such as U.S. Treasury bonds, the dollar appreciates sharply. The strengthening of the dollar during GFC is driven by global deleveraging and a surge in demand for liquid, dollar-denominated assets, rather than improvements in U.S. macroeconomic fundamentals. The episode highlighted the role of the dollar as the world's primary reserve currency, where its value is often determined more by shifts in global risk sentiment than by domestic economic conditions.

Fact 2: The dollar exchange rate appreciates when the convenience yield on U.S. Treasury bonds increases.

Figure 1 shows the strong relationship between Treasury basis and the U.S. dollar exchange rate. The blue line represents the U.S. dollar price of the average of the G10 currencies (converted into real exchange rates by adjusting the relative consumer prices.) The red line presents the Treasury basis measure in (Jiang et al., 2021), defined as the difference between the yield on a 12-month U.S. Treasury bond $r_t^{\$}$ and the synthetic dollar yield with a 12-month foreign government bond yield r_t^* hedged back into dollars. The measure captures the convenience yield of the U.S. government bonds. This figure clearly illustrates that the sharp appreciation of the U.S. dollar during crsis period is associated with a large increase in the U.S. treasury basis, which implies an increase in U.S. Treasury demand during global stress.

Fact 3: Flight to safety on Treasury Bills and retrenchment on equity flows during the crisis.

The left panel of Figure 2 plots the government bond holdings of foreign countries and the U.S. The blue line shows that there is a huge boost of rest of the world buying short-term treasuries during the Crisis. It is consistent with "Flight to Safety" during GFC. On the other hand, the red dashed line shows that U.S. purchases more foreign government bonds

[3](Lilley et al., 2022) show exchange rate reconnect with global risk appetite in Figure 2, which plots the R^2 values of rolling univariate regressions of the dollar exchange rate on a constant and the contemporaneous change in six global risk proxies: "S&P500", "Treasury Premium", "GZ Spread", "VXO" ,"Global Factor" constructed by (Miranda-Agrippino & Rey, 2020) and "Intermediary Returns" proposed in (He, Kelly, & Manela, 2017). They have shown that starting 2007, there is an abrupt increase in the explanatory power of most of of the risk proxies for the dollar exchange rate.

due to the fact that U.S. has higher risk bearing capacity. Based on the graph, we can see that there is a net bond inflow to the U.S. during global stress periods. The right panel tells a different story. It shows equity retrenchment during the crisis. During the global financial crisis, both the U.S. and the rest of the world are pulling back from foreign riskier investments and are reducing their holdings of foreign equities. Retrenchment of capital flow, which is a common feature of the Global Financial Crisis, is due to higher risk aversion of investors or higher liquidity needs.

Fact 4: U.S. NFA position deteriorates and U.S. net investment income increases during the crisis.

Figure 3 plots the U.S. net foreign asset (NFA) and the U.S. net investment income. The left panel shows that the U.S. had an NFA position of about 10% of its GDP around 2007 right before the crisis hit, and the ratio kept decreasing all the way to over 40% at the end of 2018. On the other hand, the right panel presents that the net investment income follows an opposite trend. It rises from about 0.25% of the GDP to about 1.4% toward the end of the sample. We observe that the U.S. still enjoys exorbitant privilege during financial crisis since the net investment income never drops below zero despite a consistently deteriorating of NFA.

Fact 5: CIP deviations has been substantial and persistent after the global financial crisis when dollar exchange rate appreciates.

Figure 4 shows that prior to 2007, CIP deviations tended to be very small, but since then they have been large and time-varying. On one hand, a stronger dollar is often associated with global financial stress, as investors seek safety, driving up demand for dollar-denominated assets. Foreign banks found it hard to raise dollar funds in the interbank spot market during crisis and instead turned to the swap market to swap foreign currencies into dollars, which increased the cost of synthetic dollar funding. On the other hand, CIP deviations arise from limited of arbitrage due to the new bank regulations after the global financial crisis. It develops when excess demand for dollar funding through the FX swap market is absorbed by financial institutions that have limited arbitrage capacity. With reduced arbitrage activity, the market cannot correct CIP deviations effectively, causing them to persist or widen.

3 Model

I study a two-country endowment economy with two goods. The baseline model is based on (Gertler & Karadi, 2011) and is extended into a two country environment. Time is discrete and infinite. The home country is the U.S. and the foreign country represents ROW (G10 countries). For each country, there are one representative household, one unit measure of financial intermediaries and one government.

Financial intermediaries are the most important agents in the model setup. Financial intermedairies take deposits from household, and they can invest in two types of assets: risky equities and risk-free bonds issued by the government. Financial intermediary trade assets with each other in an incomplete financial market. The dmestic and foreign financial intermedairies face asymmetric leverage constraints since U.S. government bond is considered to be safer and offer more liquidity. This asymmetry is the key to generate the model mechanism.

3.1 Endowment

Aggregate risky asset in each country is exogenous and its aggregate supply is normalized to one. It can be considered as Lucas tree that produces dividends as consumption goods. Equity's productivities are denoted by Y_t and Y_t^* and follows exogenous stochastic process. Let Q_t be the price of one unit of the domestic equity, then the return on the equity $R_{K,t+1}$ is given by

$$R_{K,t+1} = \frac{Q_{t+1} + Y_{t+1}}{Q_t}.$$

Similarly, for the foreign country, the return on equity is

$$R_{K,t+1}^* = \frac{Q_{t+1}^* + Y_{t+1}^*}{Q_t^*}.$$

3.2 Household

There are two types of goods in the economy. The domestic households are endowed with good H, and the foreign households are endowed with good F. The two goods aggregate into the consumption basket $C_t = \left(\frac{C_{H,t}}{\alpha}\right)^{\alpha}\left(\frac{C_{F,t}}{1-\alpha}\right)^{(1-\alpha)}$ for the domestic country, where $C_{H,t}$ and $C_{F,t}$ are the domestic consumption of good H and F. $\alpha \in (0.5, 1]$ implies a home bias in consumption preference. Similarly, the foreign consumption aggregator is symmetric $C_t^* = \left(\frac{C_{H,t}^*}{1-\alpha}\right)^{(1-\alpha)}\left(\frac{C_{F,t}^*}{\alpha}\right)^{\alpha}$. Households have CRRA preference over their consumption basket with risk aversion γ.

The domestic household solves the following optimization problem:

$$\max_{C_{H,t},C_{F,t},D_t} E_t \sum_{k=0}^{\infty} \beta^k \frac{C_{t+k}^{1-\gamma} - 1}{1-\gamma}$$

$$s.t. \quad C_t + D_t = R_{D,t-1}D_{t-1} + \Pi_t - T_t \tag{1}$$

The consumption basket is the numeraire. Let $P_{H,t}$ and $P_{F,t}$ be the prices of good H and F. We must have that $P_{H,t}C_{H,t} + P_{F,t}C_{F,t} = C_t$. D_t is the deposit by households at time t, $R_{D,t-1}$ is the return on risk-free deposit. In this model, I assume that households only save deposits in financial intermediaries, and they don't have access to risky financial assets nor government issued bonds directly. This assumption follows the literature on intermediary asset pricing. Households rarely directly trade sophisticated assets due to lack of investment expertise. Π_t denotes the net profit from financial intermediaries. T_t is the net tax paid to the government or net transer from the government.

Given household's optimality conditions, demand for home and foreign goods must satisfy

$$C_{H,t} = \frac{\alpha C_t}{P_{H,t}} \tag{2}$$

$$C_{F,t} = \frac{(1-\alpha)C_t}{P_{F,t}} \tag{3}$$

$$C_{H,t}^* = \frac{(1-\alpha)S_t C_t^*}{P_{H,t}} \tag{4}$$

$$C^*_{F,t} = \frac{\alpha S_t C^*_t}{P_{F,t}} \tag{5}$$

where S_t represents the real exchange rate which is defined as the relative price of the foreign consumption basket.

Proposition 1. The real exchange rate (S_t increases means U.S. dollar depreciation) in this economy is given by

$$S_t = \left(\frac{P_{F,t}}{P_{H,t}}\right)^{(2\alpha-1)} \tag{6}$$

The proof is shown in Appendix B.1.

Domestic household's intertemporal optimality condition is

$$E_t[M_{t+1}R_{D,t}] = 1 \tag{7}$$

where M_{t+1} is the household's SDF between t and t+1 given by $M_{t+1} = \beta\left(\frac{C_{t+1}}{C_t}\right)^{-\gamma}$.

3.3 Financial Intermediary

In each country, there is a unit measure of financial intermediaries. Each intermediary runs a bank in the country. They obtain funds from households and also through internally accummulated net worth. They use these funds to finance claims on both risky assets and government issued safe bonds. At the end of one period, each banker has probability σ to continue the next period as a banker and $1-\sigma$ probability of retiring to become a household. Exiting bankers pay out their earnings to the household and are replaced by a set of entrant bankers with initial wealth given by the household.

A continuing banker faces the following balance sheet constraint:

$$Q_t K_{H,i,t} + S_t Q^*_t K_{F,i,t} + B_{H,i,t} + S_t B_{F,i,t} = N_{i,t} + D_{i,t} \tag{8}$$

Here $N_{i,t}$ is the net worth, $D_{i,t}$ is the household's deposit. On the asset side, the intermediary holds $K_{H,i,t}$ unit of home equity priced at Q_t, $K_{F,i,t}$ unit of foreign equity priced at Q^*_t in foreign currency, $B_{H,i,t}$ amount of home government bond and $B_{F,i,t}$ amount of foreign government bond.

If he continues as a banker at the end of the period, his net worth evolve as

$$N_{i,t+1} = R_{K,t+1} Q_t K_{H,i,t} + S_{t+1} R^*_{K,t+1} Q^*_t K_{F,i,t} + R_{B,t} B_{H,i,t} + S_{t+1} R^*_{B,t} B_{F,i,t} - R_{D,t} D_{i,t} \quad (9)$$

where $R_{K,t+1} = (Q_{t+1} + Y_{t+1})/Q_t$ and $R^*_{K,t+1} = (Q^*_{t+1} + Y^*_{t+1})/Q^*_t$ are the returns on the doemstic and foreign equities.

The intermediary's objective is to choose his portfolio allocation to maximize the discounted expected lifetime profit. Assume the intermediary inherited the SDF M_{t+1} from the home representative household. The intermediary's value function is given as follows:

$$V(N_{i,t}) = \max_{K_{H,i,t}, K_{F,i,t}, B_{H,i,t}, B_{F,i,t}, D_{i,t}} E_t \left[M_{t+1}((1-\sigma) N_{i,t+1} + \sigma V(N_{i,t+1})) \right] \quad (10)$$

Financial intermedairy maximizes the value function by choosing the amount of equities, government bonds and deposits. Aside the balance sheet constraint shown in Eq. (8), I assume the banks face an additional leverage constraint that limits the bank's ability to raise funds.

$$V(N_{i,t}) \geq \theta_t(x_t)(Q_t K_{H,i,t} + Q^*_t S_t K_{F,i,t}) \quad (11)$$

The last inequality states that the market value of an intermediary must be greater than or equal to a fraction θ_t of its risky positions. It characterizes the VaR financing constraint faced by the intermediary which effectively limits its ability to raise funds. VaR is defined as the worst-case loss such that a loss greater than the VaR is low-probability event. $\theta_t(x_t)$ can be interpreted as VaR per unit of asset. Compared to the financial constraint in (Gertler & Karadi, 2011), $\theta_t(x_t)$ is time-varying and it is a function depending on how many safe assets in the financial intermedairy's portfolio instead of a constant. The functional form of $\theta_t(x_t)$ is defined as follows:

$$\theta_t(x_t) = \theta_0 \chi_t \exp\left(- \left(\omega_H \frac{B_{H,i,t}}{N_{i,t}} + \omega_F \frac{S_t B_{F,i,t}}{N_{i,t}} \right) \right) \quad (12)$$

where $x_t = \omega_H \frac{B_{H,i,t}}{N_{i,t}} + \omega_F \frac{S_t B_{F,i,t}}{N_{i,t}}$ is the weighted government bond holding scaled by bank's net worth. θ_0 captures the financing constraint caused by time-invariant frictions. χ_t is an exogenous stochastic state variable governing the general financial tightness. Government bonds are considered to be collateral assets. The more collateral assets the intermediary have, the more faith the depositors would have on the financial intermediary, and the VaR per unit of asset would be lower. Parameter ω_H reflects the elasticity of domestic tightness to domestic safe asset holding in the portfolio, whereas ω_F denotes the elasticity of domestic tightness to foreign safe asset holding in the portfolio. I assume that $\omega_H > \omega_F$, so that the leverage constraint is more elastic to change on the domestic safe asset holding.

Foreign leverage constraint is defined in the similar way as:

$$V(N^*_{i,t}) \geq \theta^*_t(x^*_t)(Q_t K^*_{H,i,t}/S_t + Q^*_t K^*_{F,i,t}) \tag{13}$$

where $\theta^*_t(x^*_t)$ is similarly defined as follows

$$\theta^*_t(x^*_t) = \theta^*_0 \chi_t \exp\left(-\left(\omega^*_H \frac{B^*_{H,i,t}/S_t}{N^*_{i,t}} + \omega^*_F \frac{B^*_{F,i,t}}{N^*_{i,t}}\right)\right) \tag{14}$$

I assume that $\omega^*_H > \omega^*_F$ such that foreign financial constraint is more elastic to domestic safe asset holdings than their own government bond.

The home financial intermediary has the optimization problem of maximizing Eq. (10) under the balance sheet constraint Eq. (8), the leverage constraint Eq. (11) and the law of motion of net worth Eq. (9). Before proceeding to the solution, I first introduce some lemmas which can simplify the derivation.

Lemma 1. The leverage constraints for both countries are binding if and only of there exist a positive yield spread for market risk-free security and the government bond $R_{D,t} - R_{B,t} > 0$ and $R^*_{D,t} - R^*_{B,t} > 0$.

Proof. See Appendix B.2.

Since we observe yield spreads in the data, I assume that the leverage constraints always bind.

Lemma 2. The value function for the financial intermediaries is linear in net worth. For domestic one, we have

$$V(N_{i,t}) = \psi_t N_{i,t}$$

where ψ_t is non-bank-specific. All the policy functions are also linear in net worth. Thus, financial intermediaries are homogeneous and behave exactly the same in equilibrium. Proof. See Appendix B.3.

Now, we can proceed to solve for intermediary's problem and derive key asset pricing equations. Let $\hat{M}_{t+1} = M_{t+1}(1 - \sigma + \sigma\psi_{t+1})$ be the distorted pricing kernal for the home intermedairies, and κ_t be the Lagrange multiplier associated to the domestic financial constraint. Define the leverage, denoted by ϕ_t as $\phi_t \equiv \frac{Q_t K_{H,t} + S_t Q_t^* K_{F,t}}{N_t}$. Then, we can solve for the UIP condition and real exchange rate from the first order conditions of the intermedairy's problem. I use lower case variables to represent the log of these variables.

Proposition 2. The asset pricing equations for the model are as follows:

1. From the domestic country's perspective:

    - The risk premium on the risky equity is given by

$$E_t[\hat{M}_{t+1}(R_{K,t+1} - R_{D,t})] = \kappa_t \theta_t \tag{15}$$

    - The liquidity premium for the U.S. Treasury bond is given by

$$E_t[\hat{M}_{t+1}(R_{D,t} - R_{B,t})] = \omega_H \kappa_t \theta_t \phi_t \tag{16}$$

2. Assume that $\hat{M}_{t+1}$, $\hat{M}^*_{t+1}$ and S_{t+1} follow log-normal distributions. Uncovered interest parity condition can be derived as follows.

$$\begin{aligned} E_t[\Delta s_{t+1}] + r^*_{B,t} - r_{B,t} = & \underbrace{-Cov_t(\hat{m}_{H,t+1}, \Delta s_{t+1}) - \frac{1}{2}Var_t(\Delta s_{t+1})}_{\text{risk premium adjusted by the Jensen term}} \\ & + \underbrace{\log(\mu_t - \omega_F \kappa_t \theta_t \phi_t) - \log(\mu_t - \omega_H \kappa_t \theta_t \phi_t)}_{\text{relative convenience yield gap}} \end{aligned} \tag{17}$$

Proof. See Appendix B.4.

Eq. (15) prices the risk premium due to the leverage constraint. It depends on two terms. κ_t is the Lagragian multiplier on the leverage constraint. If it is high, it represents that the financial conditions are really tight. θ_t is the per unit VaR. If it is high, then the creditor would demand a higher risk premium.

Eq. (16) prices the liquidity premium provided by the U.S. Treasury bond. If the U.S. Treasury bond does not offer any liquidity benefit, then the right hand side of the equation $\omega_H \kappa_t \theta_t \phi_t$ would be zero. Now the liquidity of U.S. Treasury bonds depends on four quantities. The first term is a constant parameter ω_H, which is the elasticity of how much the constraint reacts to change in U.S. Treasury holding. The second term κ_t is the Lagrange multiplier on the leverage constraint, which is the marginal gain of the expected present discounted profit in the objective function. The third term θ_t evaluates the time-varying tightness of the leverage constraint. The last term ϕ_t is the financial intermediary's leverage. During financial crisis periods, the leverage constraint is tightened more, all three terms κ_t, θ_t and ϕ_t would increase, and it implies a higher liquidity premium of the U.S. Treasury bond.

The second part of Proposition 2 characterizes the relations among the expected currency appreciation rate $E_t[\Delta s_{t+1}]$, the risk free rate differential $r^*_{B,t} - r_{B,t}$, the covariance between the financial intermediaries' stochastic discount factor and the real exchange rate adjusted by Jensen term $-Cov_t(\hat{m}_{H,t+1}, \Delta s_{t+1}) - \frac{1}{2}Var_t(\Delta s_{t+1})$, and the relative convenience yield gap $\log(\mu_t - \omega_F \kappa_t \theta_t \phi_t) - \log(\mu_t - \omega_H \kappa_t \theta_t \phi_t)$. The excess return term has been extensively studied[4]. The key term in Eq. (17) is the relative convenience yield gap term, which provides micro foundation for the term $(\lambda_t^{\$,\$} - \lambda_t^{*,\$})$ from (Jiang et al., 2021)[5]. It is the extra convenience yield earned by U.S. investors on their holdings of U.S. Treasurys

[4]See (Backus, Foresi, & Telmer, 2001); (Lustig, Roussanov, & Verdelhan, 2011); (Verdelhan, 2010); (Bansal & Shaliastovich, 2013); (Ready, Roussanov, & Ward, 2017) and (Lustig, Stathopoulos, & Verdelhan, 2019).

[5](Jiang et al., 2021) assume that The U.S. investors derive a convenience yield when investing in U.S. Treasurys: $E_t(M^{\$}_{t+1} e^{y^{\$}_t}) = e^{-\lambda_t^{\$,\$}}, \quad \lambda_t^{\$,\$} \geq 0$. The U.S. investor's Euler equation when investing in the foreign bond to derive a convenience yield $\lambda_t^{*,\$}$: $E_t\left(M^{\$}_{t+1} \frac{S_{t+1}}{S_t} e^{y^*_t}\right) = e^{-\lambda_t^{*,\$}}, \quad \lambda_t^{*,\$} \geq 0$. Log-linearizing the above equations, we have $E_t(\Delta s_{t+1}) + (y^*_t - y^{\$}_t) = RP^{\$}_t - \frac{1}{2}var_t(\Delta s_{t+1}) + (\lambda_t^{\$,\$} - \lambda_t^{*,\$})$, where $RP^{\$}_t - \frac{1}{2}var_t(\Delta s_{t+1})$ represent the risk premium adjusted by Jensen terms.

in excess of the foreign government bond.

To interpret the results, first we take a look at the term $\log(\mu_t - \omega_H \kappa_t \theta_t \phi_t)$ which corresponds to the term $-\lambda_t^{\$,\$}$ in (Jiang et al., 2021). It represents the convenience yield of investing in U.S. treasurys for U.S. investors. Note that μ_t is the expected return from holding risk-free market security for U.S. investors, and $\omega_H \kappa_t \theta_t \phi_t$ represents the liquidity premium offered by U.S. Treasury bonds due to safety and liquidity of the U.S. Treasury bonds. Consistent with (Jiang et al., 2021), convenience yield of investing in U.S. Treasury bonds for U.S. investors is defined as the return on holding U.S. Treasury bonds, which equals to the return from holding a risk-free market security minus the non-pecuniary benefits investors receive or the additional benefits of safety and liquidity provided by the U.S. Treasury bond. [6] Similarly, $\omega_F \kappa_t \theta_t \phi_t$ corresponds to the liquidity premium offered by foreign government bonds. Thus, $\log(\mu_t - \omega_F \kappa_t \theta_t \phi_t)$ represents the convenience yield derived from holding foreign government bond for U.S. investors. The key asymmetry is captured by parameter ω_H and ω_F. U.S. Treasury is considered to be safer and offers more liquidity, ω_H is assumed to be larger than ω_F in this model since a larger value relaxes the leverage constraint more during crisis. Therefore, this model provides micro foundation to the theoretic model of convenience yield constructed by (Jiang et al., 2021).

If both U.S. Treasury bonds and foreign government bonds offer no additional liquidity benefits, then the relative convenience yield gap term would be zero, which means that $\omega_H \kappa_t \theta_t \phi_t$ and $\omega_F \kappa_t \theta_t \phi_t$ would be zero. It can be shown that convenience yield gap term increases when there is a financial stress which leads all three terms κ_t, θ_t and ϕ_t to increase. Thus, UIP deviation becomes larger during global financial crisis period. The next proposition relates the relative convenience yield gap to the real exchange rate level.

Proposition 3. Assume that the real exchange rate is stationary with the long-run value

[6] In this paper, I follow the definition of convenience yield as in (Jiang et al., 2021). The terms convenience yield and liquidity yield are often used interchangeably in the literature which refers to the non-pecuniary benefits investors receive beyond its expected return.

$\bar{s}$. The level of the real exchange rate follows

$$\begin{aligned} s_t =& E_t \sum_{k=0}^{\infty} (r^*_{B,t+k} - r_{B,t+k}) + E_t \sum_{k=0}^{\infty} Cov_{t+k}(\hat{m}_{t+k+1}, \Delta s_{t+k+1}) \\ &- E_t \sum_{k=0}^{\infty} [\log(\mu_{t+k} - \omega_H \kappa_{t+k} \theta_{t+k} \phi_{t+k}) - \log(\mu_{t+k} - \omega_F \kappa_{t+k} \theta_{t+k} \phi_{t+k})] + \bar{s} \end{aligned} \tag{18}$$

Proposition 3 can be directly derived from Proposition 2 by iterating Eq. (17) forward. During global financial crisis periods, relative convenience yield gap increases, $\log(\mu_t - \omega_F \kappa_t \theta_t \phi_t) - \log(\mu_t - \omega_H \kappa_t \theta_t \phi_t)$ becomes larger. Since the leverage constraint tightness is persistent, the sum of future $\log(\mu_t - \omega_F \kappa_t \theta_t \phi_t)$ is higher than that of $\log(\mu_t - \omega_H \kappa_t \theta_t \phi_t)$. Therefore, U.S. dollar appreciates during global financial crisis periods.

Aggregation

At each period, a fraction $1 - \sigma$ of the financial intermediaries retire and the rest σ will continue as banker and they will carry the entire net worth they earned from previous period. The retired intermediaries will be replaced by new entrant with initial wealth provided by the household which equal to a fraction ξ of the current value of the capital stock in the previous period. For new domestic financial intermediaries, their total start-up fund is $\xi(Q_{t-1}K_{H,t-1} + Q^*_{t-1}K_{F,t-1})$. Then, we have law of motion for aggregate financial intermediary's net worth $N_t \equiv \int N_{i,t} di$

$$\begin{aligned} N_t =& \sigma[R_{K,t}Q_{t-1}K_{H,t-1} + S_t R^*_{K,t} Q^*_{t-1} K_{F,t-1} + R_{B,t-1}B_{H,t-1} + S_t R^*_{B,t-1} B_{F,t-1} - R_{D,t-1}D_{t-1}] \\ &+ \xi(Q_{t-1}K_{H,t-1} + Q^*_{t-1}K_{F,t-1}) \end{aligned} \tag{19}$$

For the domestic country, the aggregate net profit flowing into household is

$$\begin{aligned} \Pi_t =& (1-\sigma)[R_{K,t}Q_{t-1}K_{H,t-1} + S_t R^*_{K,t} Q^*_{t-1} K_{F,t-1} + R_{B,t-1}B_{H,t-1} + S_t R^*_{B,t-1} B_{F,t-1} \\ &- R_{D,t-1}D_{t-1}] - \xi(Q_{t-1}K_{H,t-1} + Q^*_{t-1}K_{F,t-1}) \end{aligned} \tag{20}$$

3.4 Government

The government in each country issues one-period risk-free bond that can only be purchased by financial intermediaries of both countries. Domestic government faces the budget constraint

$$R_{B,t}B_{G,t} \leq B_{G,t+1} + T_t$$

Here $B_{G,t}$ is the total supply of domestic government bond (safe asset), and T_t is the amount of tax or subsidy to the households. Foreign government has symmetric budget constraint. In the model, I assume the supply of government bond is constant since I want to emphasize the key mechanism of the safe asset demand. Hence, we have that $B_{G,t} = \bar{B}_G \; \forall \, t$.

3.5 Market Clearing and Equilibrium

Deposit market clearing requires that the amount supplied by households in each country equals amount demanded by financial intermediaries:

$$D_{H,t} = \int D_{H,i,t} di \quad \text{and} \quad D_{F,t} = \int D_{F,i,t} di$$

Risky assets from both countries can be held by both domestic and foreign financial intermediaries, so we have that

$$K_{H,t} + K^*_{H,t} = 1 \quad \text{and} \quad K_{F,t} + K^*_{F,t} = 1$$

Government bonds market clearing condition:

$$B_{H,t} + B^*_{H,t} = \bar{B}_G \quad \text{and} \quad B_{F,t} + B^*_{F,t} = \bar{B}^*_G$$

Resource constraints are

$$C_{H,t} + C^*_{H,t} = Y_t \quad \text{and} \quad C_{F,t} + C^*_{F,t} = Y^*_t$$

The competitive equilibrium consists of a set of allocations and prices that satisfy several conditions. First, both domestic and foreign Households solve utility maximizing problems. Second, Financial intermediaries solve profit maximization problems. Third, the government in each country chooses the amount of tax to satisfy its budget constraint. Fourth, all market clearing conditions must hold.

3.6 Bond Flows and U.S. External Balance Sheet

The model connects exchange rate movements to bond holdings, which allows me to explore the relationship between net bond flows and real exchange rate under different shocks. Let NPB_t denote the U.S. net purchase of foreign bond:

$$NPB_t = S_t(B_{F,t} - B_{F,t-1}R^*_{B,t-1}) \tag{21}$$

and let NPB^*_t denote the foreign's net purchase of U.S. bond:

$$NPB^*_t = B^*_{H,t} - B^*_{H,t-1}R_{B,t-1} \tag{22}$$

Both flows are in U.S. consumption baskets. A positive NPB^*_t means the foreign financial intermediaries purchase more U.S. bond, and a positive NPB_t means the U.S. financial intermediaries purchase more foreign bond. Then, I define the net bond flows from the foreign country to the U.S. as their difference:

$$F_t = NPB^*_t - NPB_t \tag{23}$$

which is positive when the foreign financial intermediaries buy more U.S. bond (NPB^*_t increases) or the U.S. financial intermediaries sell some foreign bond (NPB_t decreases).

For further analysis of the U.S. external balance sheet, it is useful to define the following concept within the model context.

Trade Balance: the trade balance equals exports minus imports:

$$TB_t = P_{H,t}C^*_{H,t} - P_{F,t}C_{F,t} \tag{24}$$

Net Foreign Asset: It is the foreign assets minus its total foreign liabilities. In the model, it is defined as:

$$NFA_t = S_t Q^*_t K_{F,t} - Q_t K^*_{H,t} + S_t B_{F,t} - B^*_{H,t} \tag{25}$$

Net Investment Income: The net investment income is defined as the net flow payment in one period due to the gross asset and liability positions. In the model, it is defined as:

$$\begin{aligned} NII_t =& S_t(R^*_{K,t} - 1)K_{F,t-1} - (R_{K,t} - 1)K^*_{H,t-1} \\ &+ S_t(R^*_{B,t-1} - 1)B_{F,t-1} - (R_{B,t-1} - 1)B^*_{H,t-1} \end{aligned} \tag{26}$$

3.7 Shocks

There are two sources of shocks in the model. The first one is the global financial shock. It is assumed to follow a log AR(1) process.

$$\log(\chi_t) = \rho_\chi \log(\chi_{t-1}) + \sigma_\chi \epsilon_{\chi,t} \tag{27}$$

The second one is the endowment shock on the output of the risky assets. It also follows a log AR(1) process.

$$\log(Y_t/\bar{Y}) = \rho_Y \log(Y_{t-1}/\bar{Y}) + \sigma_Y \epsilon_{Y,t} \tag{28}$$

$$\log(Y^*_t/\bar{Y^*}) = \rho^*_Y \log(Y^*_{t-1}/\bar{Y^*}) + \sigma^*_Y \epsilon_{Y,t} \tag{29}$$

In the model, $\{\epsilon_{Y,t}, \epsilon_{\chi,t}\}$ are exogenous independent drawn from standard normal distribution with mean 0 and variance 1. [7] Both of the shocks are aggregate shocks that hit both countries symmetrically.

[7] The two shocks are assumed to be independent to highlight the unique mechanism through the financial shock. In reality, those two shocks can be correlated.

4 Quantitative Analysis

I calibrate the model to match U.S. moments, and I think of Home country as the U.S. (Home) and Foreign country as the rest of the world (G10)[8]. The model frequency is quarterly. The data period is from 2000-2017. First, I outline the data sources which are used in the numerical analysis. A detailed summary of data construction is included in Appendix C.

U.S. and G10 countries' Treasury holding and equity holding data are obtained from Treasury International Capital (TIC). Treasury bond rate and G10 countries' government bond rates are from Bloomberg. U.S. risk free rate is taken from Datastream. I use bank's ROA as proxy for the equity risk premium.

To measure convenience yield difference, I follow (Jiang et al., 2021) to construct Treasury basis x_t^{Treas} using the 12-month government bond yields and forward for each currency as follows

$$x_t^{Treas} \equiv r_t^{\$} + (f_t - s_t) - r_t^* \tag{30}$$

Note that, s_t denotes the log of the nominal exchange rate in terms of foreign currency per dollar, and f_t denotes the log of the forward exchange rate. Treasury basis x_t^{Treas} measures the difference between the yield on a 12-month U.S. Treasury bond $r_t^{\$}$ and the synthetic dollar yield with a 12-month foreign government bond yield r_t^* hedged back into dollars. A negative Treasury basis means that U.S. Treasury offers liquidity yield relative to their foreign counterparts[9]. Let $r^{\$} - \bar{r}_t^{\$}$ refer to the cross-sectional average of government bond yield differences, and let $\bar{s}_t$ and $\bar{f}_t$ refer to the equally weighted cross-sectional average of log nominal spot exchange rate and forward rate against the dollar respectively. Then, cross-sectional mean Treasury basis for G10 countries can be constructed following Eq. (30) and denoted as $\bar{x}_t^{Treas}$.

[8]G10 countries refers to Australia, Canada, Denmark, Euro Zone, Japan, New Zealand, Sweden, Norway, Switzerland and United Kingdom.

[9]See (Jiang et al., 2021), convenience yield gap can be estimated from the Treasury basis. In their theory, $x_t^{Treas} \equiv -(1-\beta^{\$})\left(\lambda_t^{\$,\$} - \lambda_t^{*,\$}\right)$ where $\beta^{\$}$ is a parameter that measures the fraction of convenience gained, relative to the U.S. Treasury bond, by converting the foreign government bond into a dollar payoff.

I use IMF BOP database to obtain the external balance sheet of the U.S. , including net foreign asset position (NFA) and net investment income (NII). To construct the data moments, I normalize all quantities by U.S. GDP whenever possible. Bank's leverage ratio (ϕ_t) are taken from the Federal Reserve Board.

4.1 Calibration

The parameters of the model are summarized in Table 1. Some of the parameters are externally set to be in line with standard literature values. Model specific parameters are jointly calibrated to be matched with long-term average in the data.

On the household side, I set the home and foreign discount factor β and β^* to be 0.978 and 0.9766 to match with the U.S. and foreign market risk-free rate. The home bias parameter α is calibrated at 0.9, which is consistent with the literature. The CRRA risk aversion coefficient γ is set at 3.

On the financial intermediary side, the parameter (θ_0, θ_0^*, ω_H, ω_H^*, ω_F, ω_F^*, ξ, ξ^*) are unique in this model and are key parameters to generate the distortion for the asset prices. Parameters (θ_0, θ_0^*, ω_H, ω_H^*, ω_F, ω_F^*, ξ, ξ^*) are jointly calibrated to match the U.S. Treasury basis of the government bond of -0.0031 for a quarterly rate, equity premium of 0.0102 from the bank's quarterly ROA data, liquidity premium of 0.0028, the U.S. financial intermediary leverage of 3.678, the relative holdings of U.S. government bond (B_H/B_H^*) of 1.902, Home intermediary's home equity share of 0.729, the ratio of U.S. NFA position and GDP of -0.261 and the ratio of U.S. net investment income and GDP of 0.0089. In Table 1, we can see that ω_H which is calibrated at 0.119, is smaller than ω_H^* which is 0.199. That is, foreign financial intermediary values the safety and liquidity of U.S. Treasury bond more than U.S. financial intermedairy. A relatively higher value of ω_H^* to ω_H is crucial to generate "flight to safety" under the financial shock. $\omega_H > \omega_F$ and $\omega_H^* > \omega_F^*$ are useful to generate convenience yield of the U.S. Treasury bond. θ_0 is slightly smaller than θ_0^* to reflect that foreign financial intermedairy is more financially constrained in equilibrium. Finally, I set the bank survival probability (σ) to be at 0.88, consistent with a steady state leverage of around 3.5.

Lastly, I also need to calibrate the shocks. For the endowment shock, I calibrate ρ_Y, σ_Y from the U.S. GDP data, ρ_Y^* and σ_Y^* from G10 countries' GDP data. I take out the linear trend for the log of GDP and run an AR(1) autoregression to get the value of ρ_Y and ρ_Y^*, which are 0.955 and 0.955. Then I compute the regression residuals and take standard deviation to get the value of σ_Y and σ_Y^* which are 0.005 and 0.005, implying that the quarterly volatility of 0.5%. Since financial tightness can not be observed using data directly, I can no longer calibrate the shock parameters independently from the data. Therefore, I use simulated method of moments to determine the value of ρ_χ and σ_χ to match the volatility of a subset of variables: the exchange rate growth, the Treasury basis, the net foreign asset and the net investment income. I set $\rho_\chi = 0.98$ and $\sigma_\chi = 0.0055$.

4.2 Steady State Values

The model is solved by linearizing around the non-stochastic steady state. For the UIP condition and real exchange dynamics, there is no risk premium and we can solely focus on the mechanism via convenience yield. Table 2 presents some steady state values using the calibrated parameters listed in Table 1. The complete set of model equations and steady state conditions are shown in Appendix A.

The only asymmetry of the model are the parameters on sensitivity of government bonds in the time-varying leverage constraints. As shown above, I have $\omega_H^* > \omega_H > \omega_F^* > \omega_F$ since it is assumed in the model that U.S. government bond is safer and offers more liquidity than foreign government bond. With these calibrated parameters, we are able to generate that U.S. has a government bond rate (1.0180) which is lower than the foreign government bond (1.0213) rate by 0.0033. This is the steady state Treasury basis since $E_t s_{t+1} - s_t = 0$ at steady state. This demonstrates that there is convenience yield from holding U.S. Treasury bond. Additionally, the model could also generate a negative NFA position for the U.S. in steady state at -0.2492, meaning that U.S. has a net liability to the rest of the world. However, despite the net liability, the U.S. has a steady state trade balance deficit and a positive steady state net investment income. Since U.S. pays lower interest rate on its liability to the rest of the world than the rest of the world pays to the U.S, there is a seigniorage revenue due to convenience yield for the U.S, which allows U.S. to have a higher steady state consumption level than foreign countries as well. Moreover, the external equity share (defined as foreign equity divided by the sum of foreign equity and foreign bond holdings) of the U.S. is higher than the foreign country. This means that the U.S. earns a higher return on foreign assets due to the equity premium. Combining these features, we can see that U.S. enjoys an exorbitant privilege during normal times, which is consistent with (Gourinchas & Rey, 2022). Lastly, on the financial side, the U.S. intermediaries have a higher leverage than the foreign intermedairies in steady state. The U.S. intermediaries have less tight leverage constraint, reflected by a lower κ in the steady state.

4.3 Impulse Response of Global Financial Shock

4.3.1 Exchange Rate, Convenience Yields, Safe Asset and Equity Holdings

In this section, I describe impluse responses under a global aggregate financial shock with size of one standard deviation. This represents a negative shock to the banking system in each country, tightening the leverage constraints for both countries. It forces all the banks to de-lever and seek liquidity by adjusting their investment portfolio across asset classes. Figure 6 shows the impulse responses under a global financial shock.

The shock to the leverage constraint leads to an immediate appreciation of the U.S. real exchange rate by 0.6% and around 35 basis points increase for the convenience yields. We also observe that the return on U.S. relative to foreign government bonds falls in response to the global financial shock, which is consistent with the UIP equation defined in Eq. (17). The government bond yield difference must enlarge to generate a higher convenience yield on U.S. government bond. Additionally, liquidity yield which is defined as the difference between market risk-free deposit rate and the U.S. government bond rate increases upon the arrival of the financial shock. It implicates financial tightening of the intermediaries and a shortage of liquidity.

The response of κ_t and κ_t^* represent the endogenous increase in the Lagrange multipliers of the intermediaries' leverage constraints. While this increases for both countries, it increases more for the foreign intermediary (10.37%) than the U.S. intermediary (10.28%), implying that foreign intermediaries are more eager to de-lever and seek liquidity. Similarly, the response of ϕ and ϕ^* which represent financial leverage of the intermediaries both increase. Again, it increases more for the foreign intermediary than the home intermediary. We can see that x^* increases more than x due to the fact that foreign intermediary faces a tighter leverage constraint and are more eager to seek liquidity.

The asymmetric response of U.S. and foreign financial intermediaries also has a striking implication for asset holding positions. As the foreign financial intermediary relatively tightens more, we can see an increase in the foreign intermediaries' holding of the U.S. government bond (B_H^*) upon the arrival of the shock. In other words, foreign financial intermediaries buy more U.S. safe asset from the home financial intermedairies at a higher price (convenience yield is higher), which is consistent with the "flight to safety" during global recessions. It happens because foreign financial intermediary values the safety of the U.S. Treasury bonds more than U.S. financial intermediaries, which is reflected as the sensitivity parameter $\omega_H^* > \omega_H$ in the model. On the other hand, U.S. financial intermediaries are buying more foreign government bond (B_F) since their risk-bearing capacity is relatively bigger. The tightening also leads to a 4.5% drop of the equity prices for both countries. Since the home intermediary leverages more at the steady state and has a higher equity portfolio, resulting in a bigger fall in net worth following the financial tightening. When financial shock hits the economy, there is an external portfolio retrenchment on equity such that home financial intermedairy increases its demand for home equity and decreases its holding of foreign equity. The foreign financial intermedairy has the opposite reaction to the shock. Equity retrenchment is a common feature of financial crises. Since equities are risky, financial intermediaries always want to increase demand for safe assets for liquidity purposes and substitute away from equities during crisis. Additionally, due to the information asymmetric effect which always tends to be amplified during global recession, intermediaries prefer home equities over foreign equities. The uncertainty or lack of transparency in foreign markets makes their equities to be riskier, leading to retrenchment. So far, the impluse responses to financial shocks match with the stylized facts described in Section 2.

4.3.2 Net Bond Flows and U.S. External Balance Sheet

Motivated by the "exchange rate reconnect" observation that the correlation between bond flow and exchange rate strengthens after the Global Financial Crisis (Lilley et al., 2022), it is interesting to see whether this model could generate the correlation between bond flows and real exchange rate under a global financial shock. (Lilley et al., 2022) empirically show that U.S. net purchase of foreign bonds were highly correlated with the risk measures as well as with dollar exchange rate. In quarters when U.S. increases the holding of net foreign bonds, the dollar contemporaneously depreciates. When U.S. decreases these net foreign bond holdings, the dollar appreciates. From Figure 7, we can see that both NBP and NPB^* increases upon the arrival of the financial shock, but NPB^* increases relatively more. As more funds flow from the foreign country into the U.S. than the other way around, we obtain a positive net bond flow F_t to the U.S. Hence, the global financial shock which endogenously generate safe asset demand produces a positive correlation between the dollar exchange rate and the net bond flow. Intuitively, given the U.S. safe-haven status, we would expect bond flows into the U.S. during global stress periods as foreign investors seek safety and liquidity, and dollar appreciates due to high convenience yield. During normal times, dollar depreciates and there is a capital outflows from the U.S. to the rest of the world when investors are willing to take on more risks. This is consistent with a large literature that emphasizes the flow-driven mechanism of exchange rate movement.

Figure 7 also shows that U.S. NFA falls sharply by around 4.8% after the financial shock. The valuation effects are the dominant force. Due to the role of the U.S. as the "world banker" such that U.S. intermediaries issue safe liabilities primarily in dollars to foreigners but hold foreign risky assets denominated in foreign currencies, a real appreciation of the dollar will lead to the value of the U.S. foreign assets (denominated in foreign currencies) drops in dollar terms. Thus, in the flight to safety episode, the U.S. suffer a loss on its external portfolio, leading to a decline in U.S. NFA as shown in Figure 7. Meanwhile, equity prices collapses when shock arrives, which makes the value of foreign assets decreases even more. On the other hand, the value of the U.S. liabilities held by foreigners remain relatively stable or even increase due to flight to safety. (Gourinchas & Rey, 2007b) argues that if the U.S. runs a negative NFA today, it has to be offset by either positive trade balances or by positive foreign investment income. We can see from Figure 7 that the net investment income increases by 0.42% when the financial shock hits. The impluses responses are matched to all the stylized facts presented in Section 2. Additionally, if we separate net investment income into income from holding government bonds and income from holding equities, we can see that net income gain from holding bonds increases by 1.12%, which is larger than the net income loss from holding equities (-0.70%). Thus, the loss from holding risky assets could be offset by the higher seigniorage revenue from issuing safe government bond. Additionally, in Figure 7, panel $c - c^*$ shows that the U.S. households' consumption increases relative to the foreign households' consumption while the U.S. trade balance decreases by 0.93% . The increase in U.S. relative consumption and net investment income reflects a seigniorage revenue that the U.S. earns from issuing bonds that have higher convenience yields. By issuing expensive safe asset that carry high convenience yield to foreigners, the U.S. receive wealth from the rest of the world despite the loss on equity investment. In this case, a negative NFA does not require subsequent trade supluses since trade deficits are offset by the seigniorage revenue.

Under the insurance-provision view, U.S. experiences wealth loss and its consumption share goes down since U.S. suffers portfolio losses from insuring the rest of the world. (Gourinchas & Rey, 2022) refer to the wealth transfer as the exorbitant duty of the reserve asset supplier during global recessions. In my model, we observe that the foreign demand for dollar safe assets increases during global recessions, and convenience yield increases which makes the seigniorage revenue countersyclical. It allows the U.S. to consume relatively more than foreign countries in recessions. Though the U.S. still suffers portfolio losses from its external positions due to valuation effects, the increase in seigniorage revenues can offset the wealth losses and allow U.S. to run trade deficits and consume relatively more. Due to the home bias in household's consumption demand, the U.S. spends more on U.S. goods, which appreciates the dollar in real terms. Combining with the previous result that the real dollar appreciation is driven in financial markets by the rise in the convenience yield, we can see that the goods market clearing is also consistent with a stronger dollar. Therefore, the "reserve currency paradox" proposed in (Maggiori, 2017) is resolved by seigniorage revenue from safe government bonds that generate countercyclical U.S. consumption share.

4.4 Impulse Response of Global Endowment Shock

Figure 8 and Figure 9 present the impulse responses of a one standard deviation negative shock that hits the output of the risky tree. We can see that the effects on real exchange rate, asset prices, convenience yields and capital flows are mostly very similar to the effects of a global tightening of the financial constraint. This is because the endowment shock lowers the return and the price of the equity, Hence, it reduces the profitability of the financial intermediary, which shrinks the net worth of the financial intermedairies. This leads to a contraction of the economy and further impairs the intermediaries' balance sheets. As in the literature on the "financial accelerator" e.g., (Gertler & Karadi, 2011), the financial squeeze resulting from a negative endowment shock reduces investment and exacerbates the effect of the original drop in endowment of the output. Thus, a negative endowment shock endogenously tightens the leverage constraint and generate similar impulse responses. The response of all the impulse responses to the endowment shock are smaller by an order of magnitude than the responses to the global financial shock. This is because, unlike endowment shock, financial shock directly affects and tightens the leverage constraint.

4.5 Second Order Moments

In the previous subsections, we observe that the impulse response to an endowment shock is significantly weaker compared to that of a financial shock. Since the 2008 financial crisis involved both a financial crisis and a real economic recession, it is necessary to examine whether my model can effectively explain the financial crisis. In this section, I present the second order moments from the simulation results for the benchmark case and the case with only the endowment shock. The first column of Table 3 lists these moments. For the benchmark case, I target the volatility of the exchange rate growth, the bond yield difference, the net foreign asset and the net investment income to match to the data. All other moments are untargeted and are used to evaluate how well the model performs quantitatively. The second column reports their values in the data, based on the time series of the U.S. against the equal-weighted average of G10 countries from year 2000 to 2017. More detailed description of the data is shown in Appendix C.

For all the targeted moments, we can see that the benchmark model can generate very close results to the data. However, for the alternative model with only the real shock, the second order targeted moments are entirely inaccurate and generate much smaller values compared to the data. The dollar exchange rate has a volatility of 4.31% per quarter, which is very close to the volatility generated by the benchmark model (4.65%). With only the endowment shock, we can see that it is too small to generate the exchange rate volatility (1.22%). In the benchmark model, there are two sources of exchange rate fluctuations: financial shock and endowment shock. Financial shock move exchange rates through directly affecting the leverage constraint, which raises exchange rate volatility compared to other standard models with just endowment (or productivity) shocks. Similarly, the endowment shock fails to generate large enough volatility of the bond yield difference at only 0.2%, much lower than what we observe in the data (0.97%). It performs even worse on the volatility of net foreign asset and net investment income.

The benchmark model in general also performs well on all the correlations of the exchange rate comovements. The correlation between the expected change of dollar exchange rate and the bond yield difference is -0.1591 in the data. Both benchmark model and the model with only the endowment shock predict the correct sign. In the data, the U.S.-foreign government bond yield differential is less volatile than the exchange rate movement, and is negatively correlated with the dollar's expected appreciation in the next period. Thus, the model can account for Fama's forward premium puzzle. In addition, the model can produce a realistic (Backus & Smith, 1993) correlation $corr(\Delta s, \Delta c - \Delta c^*)$ of 0.1651, which is consistent with the fact that consumption growth differential is weakly correlated with the exchange rate movement. In this model, the time-varying leverage constraint introduces an addtional source of exchange rate variation. Proposition 3 explicitly highlights this new source, which operates independently of household consumption. As a result, the model relaxes the strict connection between the exchange rate and the consumption differential. The model also performs reasonably well in the correlation of the change of exchange rate with the net bond flows, which, as we discussed in the previous section, should be negative. When there is a net bond inflow into the U.S., the dollar appreciates contemporarily. The same logic applies to the correlation between the change of exchange rate and the change of foreign purchase of U.S. Treasury bond. Both models perform well and the correlations tend to be smaller for the model with just endowment shocks. Finally, the model could also effectively generate the correlation between change of exchange rate and U.S. net investment income.

5 Deviations from CIP

The benchmark framework with the asymmetric time-varying leverage constraint can generate deviations from UIP. A substantial literature has documented the CIP deviations and the role of post-2008 regulations. After the Global Financial Crisis, regulators imposed stricter leverage rules on banks to improve financial stability. However, these rules increased the cost of financial intermediation, which in turn contributed to persistent deviations from CIP. Moreover, the deviations from CIP are also correlated with dollar appreciation during global stress. A stronger dollar is often associated with global financial stress, which triggers a global flight to safety, foreign investors sell risky assets and rush into dollar denominated safe assets, leading to a severe dollar shortage. However, during financial stress, banks became reluctant to lend dollars to each other due to liquidity concerns. When foreign banks find it hard to raise dollar funds in the interbank market, they have to turn to the swap market to get synthetic dollars, resulting higher cost of synthetic dollar funding.

The baseline model can be extended by including FX swap contracts to explain deviations from CIP in post global financial crisis periods. Let FX swap be a combination of a spot transaction and a forward transaction of foreign currency. FX swap trader can borrow U.S. dollar and buy foreign currency in the foreign exchange market at the current spot exchange rate S_t, invest in the riak-free market security for a return at $R^*_{D,t}$, and sell the foreign currency after one quarter at the predetermined forward exchange rate F_t. Thus, the return on FX swap contract is $R_{S,t} = F_t R^*_{D,t}/S_t$. In the absence of arbitrage, the return from FX swap should equal to the U.S. risk-free rate, which leads to the CIP in log terms as follows

$$f_t + r^*_{D,t} - s_t - r_{D,t} = 0 \tag{31}$$

The CIP represents one of the most well-established and reliable no-arbitrage conditions in international finance. CIP held very well before the global financial crisis in 2007. However, deciations from CIP have been large and persistent after the financial crisis. (Du, Tepper, & Verdelhan, 2018) document that CIP deviation was near zero precrisis and has generally been negative for most G10 currencies since the GFC, implying that $r_{D,t} < r^*_{D,t} + f_t - s_t$ which means that the cost of borrowing dollar directly is lower than that of synthetic dollar borrowing. They show that the deviation from CIP are closely related to frictions in financial intermediary that hamper arbitrage activities.

5.1 Model extension for CIP deviation

Assume that U.S. financial intermediaries write FX swap contracts that swap U.S. dollars for foreign currencies. Let $S_{FX,t}$ denotes the U.S. intermediaries' positions on the FX swap. Then financial intermediary's optimization problem becomes:

$$V(N_{i,t}) = \max_{K_{H,i,t},K_{F,i,t},B_{H,i,t},B_{F,i,t},D_{i,t},S_{FX,i,t}} E_t\left[M_{t+1}((1-\sigma)N_{i,t+1}+\sigma V(N_{i,t+1}))\right] \tag{32}$$

where $N_{i,t+1}$ evolves as

$$\begin{aligned} N_{i,t+1} &= R_{K,t+1}Q_tK_{H,i,t} + S_{t+1}R^*_{K,t+1}Q^*_tK_{F,i,t} + R_{B,t}B_{H,i,t} \\ &+ S_{t+1}R^*_{B,t}B_{F,i,t} + R_{S,t}S_{FX,i,t} - R_{D,t}D_{i,t}. \end{aligned} \tag{33}$$

subject to

$$Q_tK_{H,i,t} + S_tQ^*_tK_{F,i,t} + B_{H,i,t} + S_tB_{F,i,t} + S_{FX,i,t} = N_{i,t} + D_{i,t} \tag{34}$$

$$V(N_{i,t}) \geq \theta_t(x_t)(Q_tK_{H,i,t} + S_tQ^*_tK_{F,i,t} + \nu S_{FX,i,t}) \tag{35}$$

where ν is the parameter governs the tightness of the constraint on FX swap position. If $\nu = 0$, the FX swap position is not constrained. If $\nu = 1$, the FX swap position has the same level of constraint with other risk assets. If $0 < \nu < 1$, the FX swap has relatively looser constraint than other risky assets.[10]

In the model, I assume that the FX swap contract is in zero net supply and that only US intermediaries write swap contracts.[11] These assumptions are made for tractability purposes such that the existence of the FX swap contract does not alter the real and financial allocations in both countries. The first-order condition with respect to $S_{FX,i,t}$ from the above optimization problem is

$$E_t\hat{M}_{t+1}R_{S,t+1} = \mu_t + \nu\kappa_t\theta_t \tag{36}$$

The CIP deviation $r_{cip,t}$ can be derived as:

$$r_{cip,t} \equiv r_{D,t} - r_{S,t} = \log(\mu_t) - \log(\mu_t + \nu\kappa_t\theta_t) \tag{37}$$

[10] I assume that the constraint is at the bank level so that the level of the constraint tightness of different risky assets comoves.

[11] This assumption can be partially motivated by the specialty of the US dollar in post financial crisis periods. (Du, Tepper, & Verdelhan, 2018) and (Ivashina et al., 2015) point out that investors from the rest of the world seek dollar funding for dollar asset investment and borrow synthetic dollars through the swap market from U.S. banks when dollar funding is limited in the spot market. Foreign investors obtain synthetic dollar funding by borrowing and converting foreign currency to U.S. dollars, and selling U.S. dollars in the future. As the counterparty, the U.S. banks provide synthetic dollar funding. The U.S. dollar funding needs are dominant, while foreign banks provide limited synthetic foreign currency funding.

From Eq. (37), whether the CIP holds depends on the constraint imposed on the swap contract. If there is no constraint ($\nu = 0$ or $\kappa = 0$), the CIP holds. Otherwise, the CIP is violated. When $\kappa_t > 0$ and $0 < \nu < 1$, we have that $r_{cip,t} < 0$, which shows that U.S. dollars are cheaper in the cash market than in the swap market (Du, Tepper, & Verdelhan, 2018). This model is also capable to rationalize the empirical findings in (Avdjiev et al., 2019) that CIP deviation is larger in absolute value when dollar is strong. When the U.S. financial intermedairies face tighter leverage constraints (the term $\kappa_t \theta_t$ increases), the deviation from CIP becomes widen. The dollar exchange rate also appreciates as shown in Proposition 3.

5.2 CIP Deviation Estimation

It is documented in the literature that large and persistent CIP deviation exist due to the changed bank regulations after the financial crisis (Boyarchenko, Eisenbach, Gupta, Shachar, & Van Tassel, 2020). Before the crisis, banks were subject to requirements regarding the risk-weighted capital ratio of tier-1 capital and risk-weighted assets. FX swaps were considered to have zero risk and were essentially unconstrained. Based on Eq. (37), $\nu = 0$ and thus CIP holds before the financial crisis. However, after the financial crisis, the Basel III framework imposes requirements on an additional supplementary leverage ratio, the ratio of tier-1 capital and total on-balance-sheet, and specific off-balance-sheet assets, including the FX swap positions. Although an FX swap is considered to have zero risk, banks are still required to reserve a portion of capital against their FX swap positions. Therefore, the FX swap positions become constrained ($\nu > 0$). Since we have both κ_t and θ_t to be positive, the CIP deviation $r_{cip,t}$ became negative after the crisis.

The relative constraint tightness of FX swap ν is identified by Eq. (37). The average CIP deviation $\log(\mu_t) - \log(\mu_t + \nu\kappa_t\theta_t)$ is -0.25% in the data, while the banks' ROA $\log(\mu_t + \kappa_t\theta_t)$ is 1.02% in the data. The estimate of the relative constraint tightness ν equals to 0.24.

The estimate is consistent with the new banking regulations. Under the new Basel III regulatory framework, banks are required to hold at least 3% of equity capital against all assets regardless of their risk levels. This requirement did not exist before the global financial crisis. For risky assets, banks face a total capital ratio of 11.5% to 15% after the financial crisis.[12] Consider the average 13.25% as the banks' capital ratio for total risky assets. The relative tightness of the constraint on risk-free FX swap position is equal to $3\%/13.25\% = 0.226$, which is close to the estimate from the data of CIP deviation and banks' ROA.

Figure 10 shows the impluse responses of CIP deviations to a global financial shock. We can see that there is a 0.23% widening of the CIP deviation upon the shock. Therefore, the model could reproduce the positive correlation between dollar exchange rate and CIP deviation.

6 Conclusion

Intermediaries are major participants in the international financial market. In this paper, I develop an open economy intermediary-based model with time-varying leverage constraint that can endogenously generate the liquidity demand for U.S. safe assets and provide micro-foundation for the convenience yield. In response to a global financial shock coming from a sudden tightening of the leverage constraints for all intermedairies, I show that the model accurately captures the stylized facts discussed in the paper. Notably, the US dollar experiences a sharp appreciation upon the arrival of the shock, which coincides with a surge in the convenience yield on US Treasuries relative to foreign government bonds. The model can qualitatively and quantitatively explain the U.S. external adjustment during the financial crisis as well. Compared to the standard view of the U.S. exorbitant privilege in the literature, which emphasizes the U.S.' role as the global insurance provider such that it has exorbitant privilege by earning risk premium during normal times and bears exorbitant duty in global downturns as insurance pays off. My model takes the

[12]See (Du, Tepper, & Verdelhan, 2018); (Boyarchenko et al., 2020); (Cenedese et al., 2021) for more details about the changes in banking regulations after the crisis.

angle from safe asset demand and highlights the seigniorage revenue the U.S. gains as the issuer of the global safe asset, enabling it to maintain a stronger currency and relative higher consumption shares during global downturns, even in the face of external portfolio losses. These results from the model shed new light on exchange rate disconnect, U.S. exorbitant privilege and the relationship between dollar exchange rate movements and cross-border bond flows. Meanwhile, the model can also jointly explain the large and persistent deviations from CIP due to bank regulations tightening during and after the global financial crisis.

This paper contributes to the intermediary asset pricing literature by demonstrating the empirical relevance of an intermediary-based model in studying exchange rate movements. Since my model is an endowment economy, my analysis does not account for how the foreign safe asset demand would affect the U.S. real economy, and what is the optimal amount of safe assets the U.S. should issue. The model framework can be extended for future analysis, including optimal policy consideration and implications for asset pricing.

References

Amador, M., Bianchi, J., Bocola, L., & Perri, F. (2020). Exchange rate policies at the zero lower bound. *The Review of Economic Studies*, *87*(4), 1605–1645.

Avdjiev, S., Du, W., Koch, C., & Shin, H. S. (2019). The dollar, bank leverage, and deviations from covered interest parity. *American Economic Review: Insights*, *1*(2), 193–208.

Backus, D. K., Foresi, S., & Telmer, C. I. (2001). Affine term structure models and the forward premium anomaly. *The Journal of Finance*, *56*(1), 279–304.

Backus, D. K., & Smith, G. W. (1993). Consumption and real exchange rates in dynamic economies with non-traded goods. *Journal of International Economics*, *35*(3-4), 297–316.

Bansal, R., & Shaliastovich, I. (2013). A long-run risks explanation of predictability puzzles in bond and currency markets. *The Review of Financial Studies*, *26*(1), 1–33.

Borio, C. E., Iqbal, M., McCauley, R. N., McGuire, P., & Sushko, V. (2018). The failure of covered interest parity: Fx hedging demand and costly balance sheets.

Boyarchenko, N., Eisenbach, T. M., Gupta, P., Shachar, O., & Van Tassel, P. (2020). Bank-intermediated arbitrage.

Caballero, R. J., Farhi, E., & Gourinchas, P.-O. (2008). An equilibrium model of "global imbalances" and low interest rates. *American economic review*, *98*(1), 358–393.

Cenedese, G., Della Corte, P., & Wang, T. (2021). Currency mispricing and dealer balance sheets. *The Journal of Finance*, *76*(6), 2763–2803.

Devereux, M. B., Engel, C., & Wu, S. P. Y. (2023). *Collateral advantage: Exchange rates, capital flows and global cycles* (Tech. Rep.). National Bureau of Economic Research.

Du, W., Im, J., & Schreger, J. (2018). The us treasury premium. *Journal of International Economics*, *112*, 167–181.

Du, W., Tepper, A., & Verdelhan, A. (2018). Deviations from covered interest rate parity. *The Journal of Finance*, *73*(3), 915–957.

Engel, C. (2016). Exchange rates, interest rates, and the risk premium. *American Economic Review*, *106*(2), 436–474.

Engel, C., & West, K. D. (2005). Exchange rates and fundamentals. *Journal of political Economy*, *113*(3), 485–517.

Engel, C., & Wu, S. P. Y. (2023). Liquidity and exchange rates: An empirical investigation. *The Review of Economic Studies*, *90*(5), 2395–2438.

Fang, X., & Liu, Y. (2021). Volatility, intermediaries, and exchange rates. *Journal of Financial Economics*, *141*(1), 217–233.

Gabaix, X., & Maggiori, M. (2015). International liquidity and exchange rate dynamics. *The Quarterly Journal of Economics*, *130*(3), 1369–1420.

Gertler, M., & Karadi, P. (2011). A model of unconventional monetary policy. *Journal of monetary Economics*, *58*(1), 17–34.

Gourinchas, P.-O., & Rey, H. (2007a). From world banker to world venture capitalist: Us external adjustment and the exorbitant privilege. In *G7 current account imbalances: sustainability and adjustment* (pp. 11–66). University of Chicago Press.

Gourinchas, P.-O., & Rey, H. (2007b). International financial adjustment. *Journal of political economy*, *115*(4), 665–703.

Gourinchas, P.-O., & Rey, H. (2022). Exorbitant privilege and exorbitant duty.

Gourinchas, P.-O., Rey, H., & Truempler, K. (2012). The financial crisis and the geography of wealth transfers. *Journal of International Economics*, *88*(2), 266–283.

He, Z., Kelly, B., & Manela, A. (2017). Intermediary asset pricing: New evidence from many asset classes. *Journal of Financial Economics*, *126*(1), 1–35.

He, Z., & Krishnamurthy, A. (2013). Intermediary asset pricing. *American Economic Review*, *103*(2), 732–770.

Itskhoki, O., & Mukhin, D. (2021). Exchange rate disconnect in general equilibrium. *Journal of Political Economy*, *129*(8), 2183–2232.

Ivashina, V., Scharfstein, D. S., & Stein, J. C. (2015). Dollar funding and the lending behavior of global banks. *The Quarterly Journal of Economics*, *130*(3), 1241–1281.

Jiang, Z. (2024). *Exorbitant privilege: A safe-asset view* (Tech. Rep.). National Bureau of Economic Research.

Jiang, Z., Krishnamurthy, A., & Lustig, H. (2021). Foreign safe asset demand and the dollar exchange rate. *The Journal of Finance*, *76*(3), 1049–1089.

Kekre, R., & Lenel, M. (2024). The flight to safety and international risk sharing. *American Economic Review*, *114*(6), 1650–1691.

Koijen, R. S., & Yogo, M. (2020). *Exchange rates and asset prices in a global demand system* (Tech. Rep.). National Bureau of Economic Research.

Krishnamurthy, A., & Lustig, H. N. (2019). Mind the gap in sovereign debt markets: The us treasury basis and the dollar risk factor. In *2019 jackson hole economic symposium, stanford university graduate school of business research paper.*

Krishnamurthy, A., & Vissing-Jorgensen, A. (2012). The aggregate demand for treasury debt. *Journal of Political Economy*, *120*(2), 233–267.

Lilley, A., Maggiori, M., Neiman, B., & Schreger, J. (2022). Exchange rate reconnect. *Review of Economics and Statistics*, *104*(4), 845–855.

Lustig, H., Roussanov, N., & Verdelhan, A. (2011). Common risk factors in currency markets. *The Review of Financial Studies*, *24*(11), 3731–3777.

Lustig, H., Stathopoulos, A., & Verdelhan, A. (2019). The term structure of currency carry trade risk premia. *American Economic Review*, *109*(12), 4142–4177.

Maggiori, M. (2017). Financial intermediation, international risk sharing, and reserve currencies. *American Economic Review*, *107*(10), 3038–3071.

Maggiori, M., Neiman, B., & Schreger, J. (2020). International currencies and capital allocation. *Journal of Political Economy*, *128*(6), 2019–2066.

Meese, R. A., & Rogoff, K. (1983). Empirical exchange rate models of the seventies: Do they fit out of sample? *Journal of international economics*, *14*(1-2), 3–24.

Mendoza, E. G., Quadrini, V., & Rios-Rull, J.-V. (2009). Financial integration, financial development, and global imbalances. *Journal of Political economy*, *117*(3), 371–416.

Miranda-Agrippino, S., & Rey, H. (2020). Us monetary policy and the global financial cycle. *The Review of Economic Studies*, *87*(6), 2754–2776.

Obstfeld, M., & Rogoff, K. (1995). Exchange rate dynamics redux. *Journal of political economy*, *103*(3), 624–660.

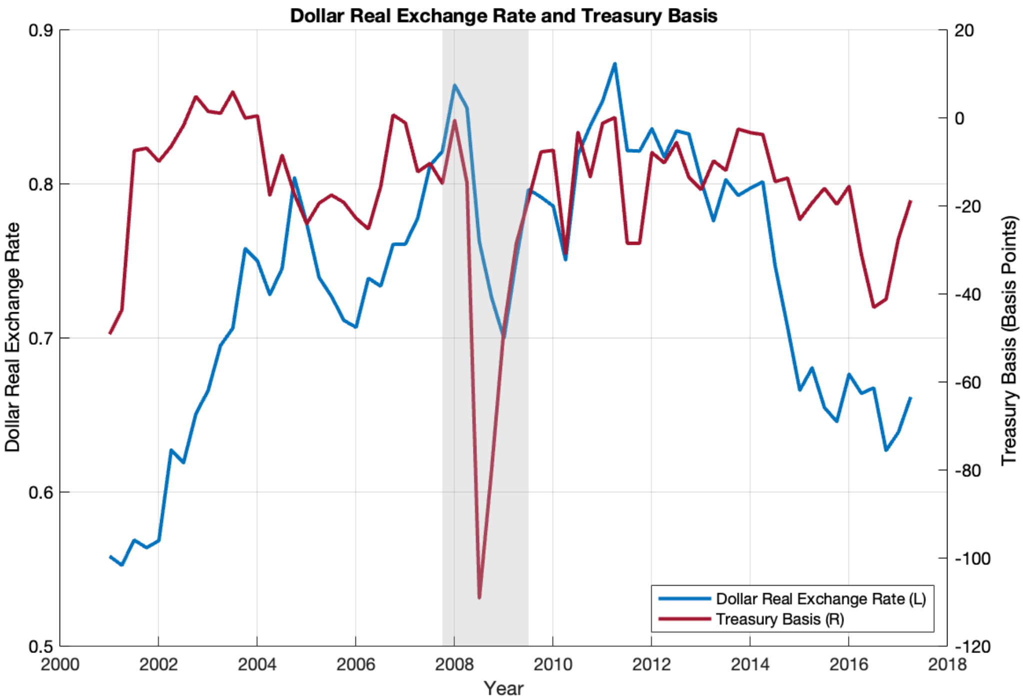
Ready, R., Roussanov, N., & Ward, C. (2017). Commodity trade and the carry trade: A tale of two countries. *The Journal of Finance*, *72*(6), 2629–2684.

Rime, D., Schrimpf, A., & Syrstad, O. (2022). Covered interest parity arbitrage. *The Review of Financial Studies*, *35*(11), 5185–5227.

Valchev, R. (2020). Bond convenience yields and exchange rate dynamics. *American Economic Journal: Macroeconomics*, *12*(2), 124–166.

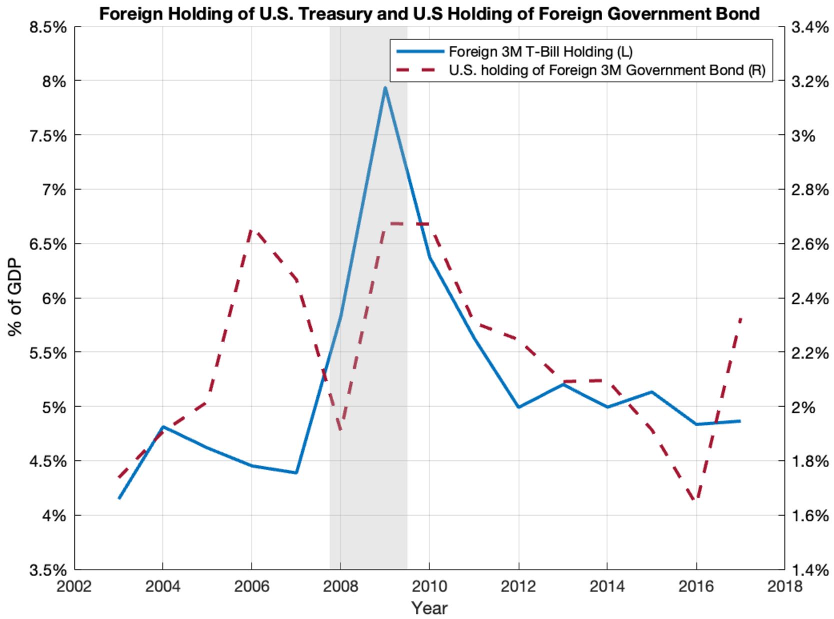
Verdelhan, A. (2010). A habit-based explanation of the exchange rate risk premium. *The Journal of Finance*, *65*(1), 123–146.

Figure 1: Dollar Exchange Rate and U.S. Treasury Basis

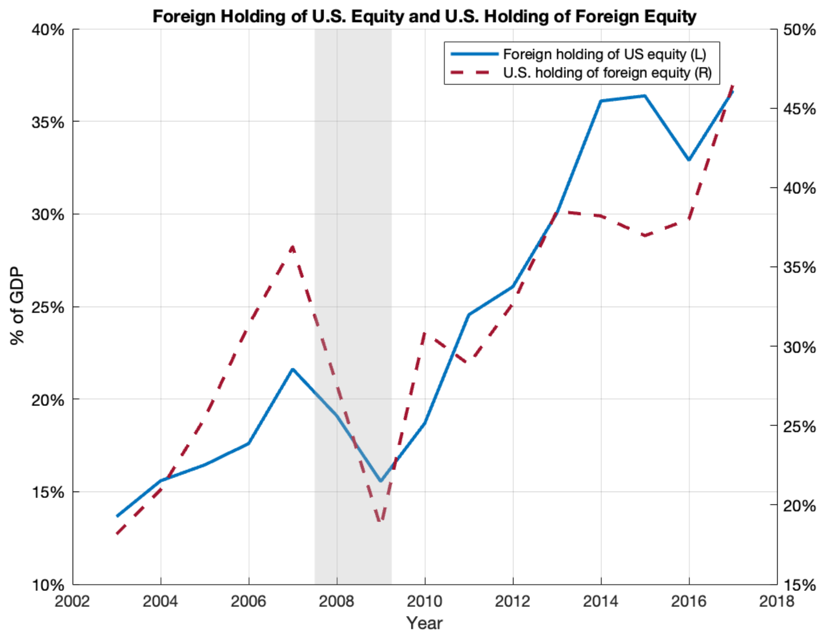


Note: Treasury basis is defined as in (Jiang et al., 2021) to measure convenience yield of holding U.S. Treasury bond. Cross-sectional mean Treasury basis for G10 countries is constructed as $\bar{x}_t^{Treas} \equiv r_t^{\$} + (f_t - s_t) - \bar{r}_t^*$. The maturity is one year. Dollar real exchange rate is the U.S. dollar price of the average of G9 currencies adjusted by price indexes.

Figure 2: Flight to Safety and Equity Retrenchment during the Global Recessions



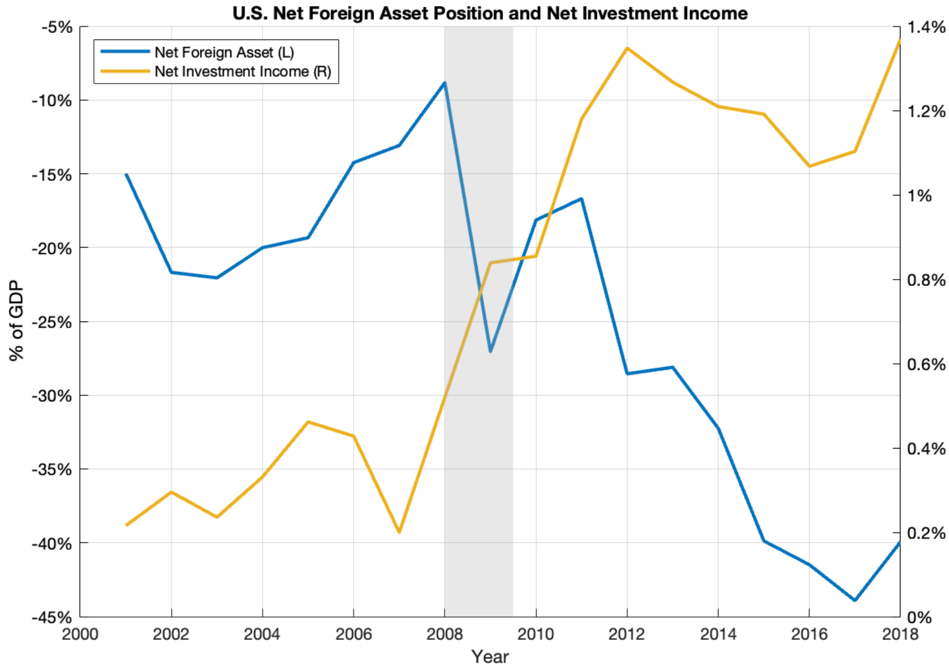
(a) Treasury bond holdings



(b) Equity holdings

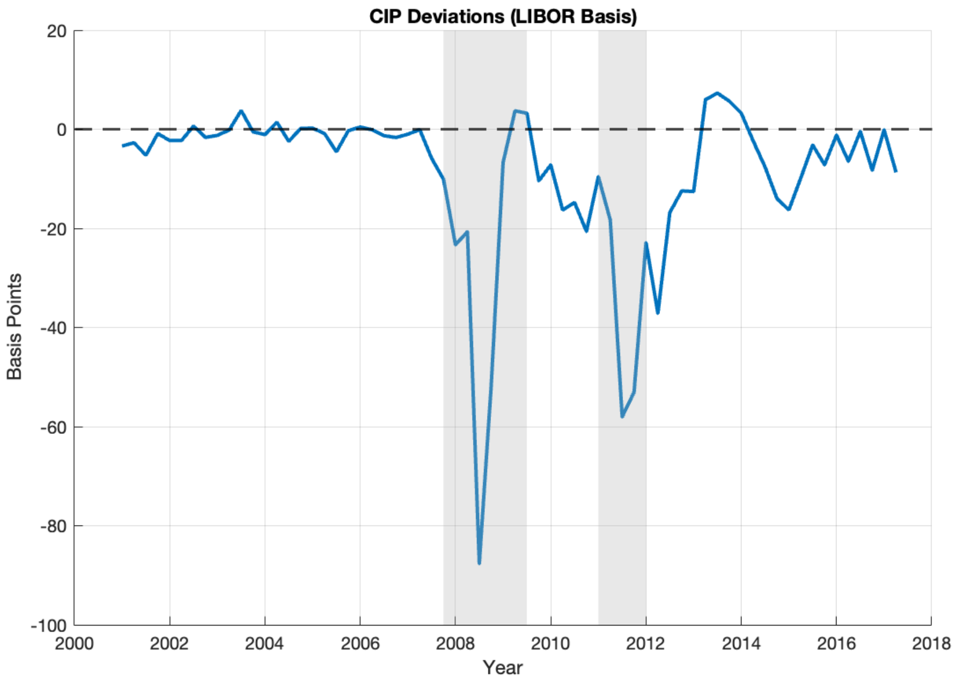
Note: Treasury bond holdings and equity holdings are in the percentage of U.S. GDP. Source: TIC.

Figure 3: U.S. Net Foreign Asset Position and Net Investment Income



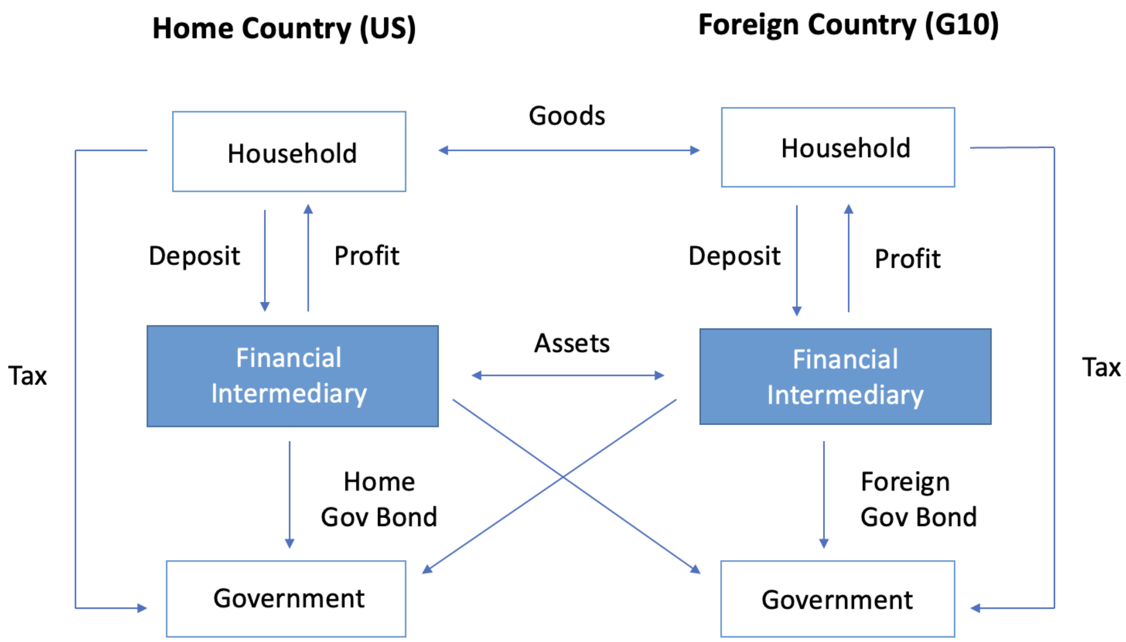
Note: Net foreign asset and net investment income are in percentage of the U.S. GDP. Source: IMF, BOP.

Figure 4: CIP Deviations (LIBOR Basis)



Note: The LIBOR basis is constructed using the 12-month yields and forward for each G10 currency following $x_t^{Libor} = y_t^{\$,Libor} - \left(y_t^{*,Libor} - (f_t - s_t)\right)$, consistent with the definition of (Du, Im, & Schreger, 2018). This figure shows the mean LIBOR basis of the U.S. dollar against the basket of G10 currencies.

Figure 5: Model Structure



Note: This figure shows the structure of the model in a circular flow diagram.

Figure 6: Impluse Response under a Global Financial Shock

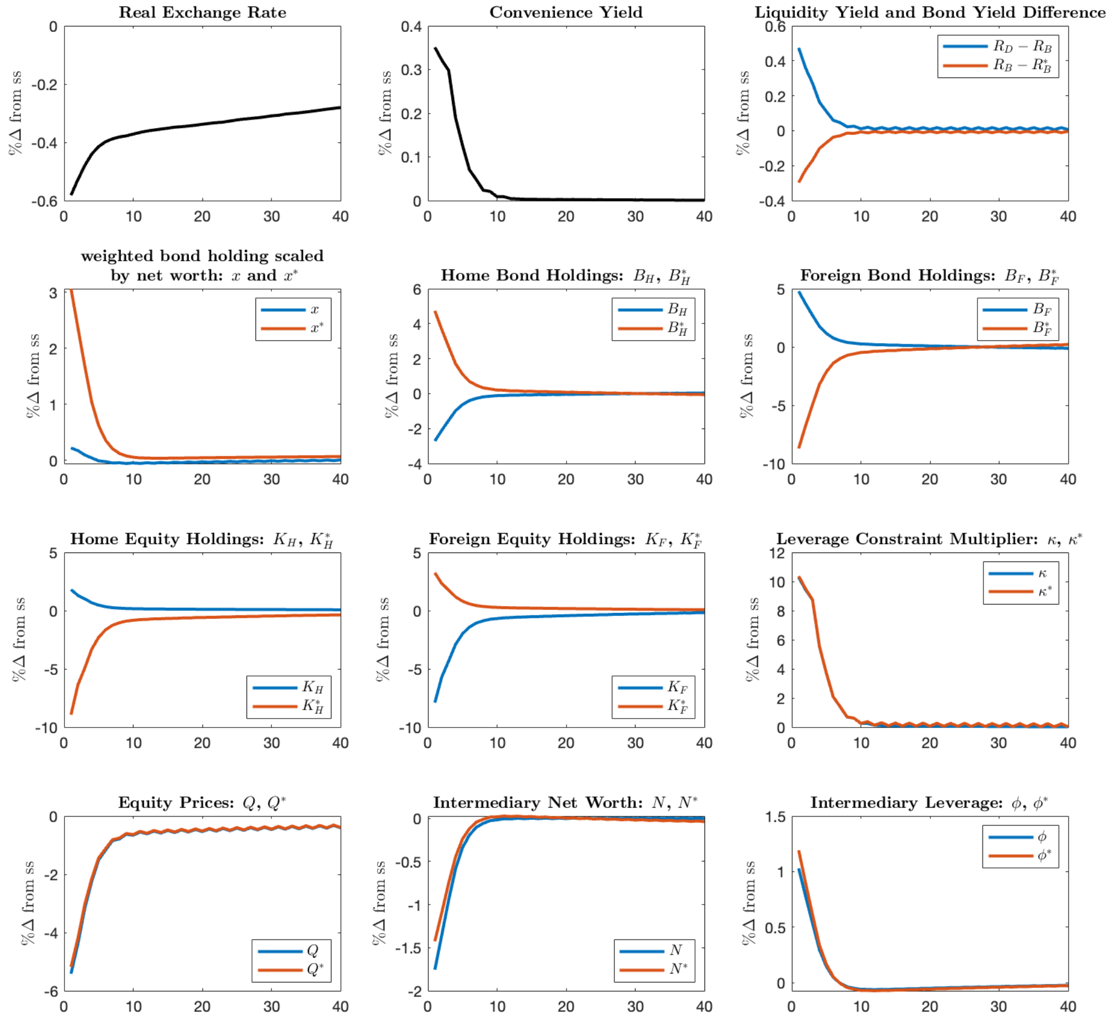


Figure 7: Impluse Response under a Global Financial Shock

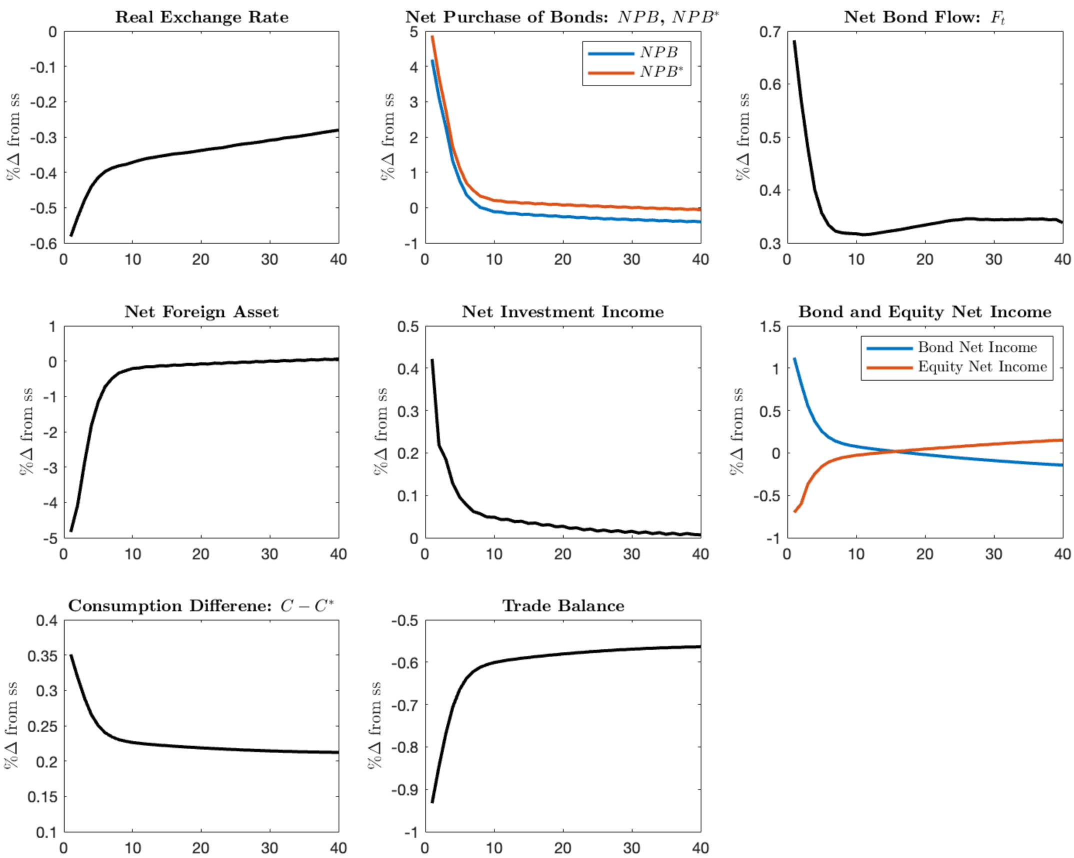


Figure 8: Impluse Response under an Endowment Shock

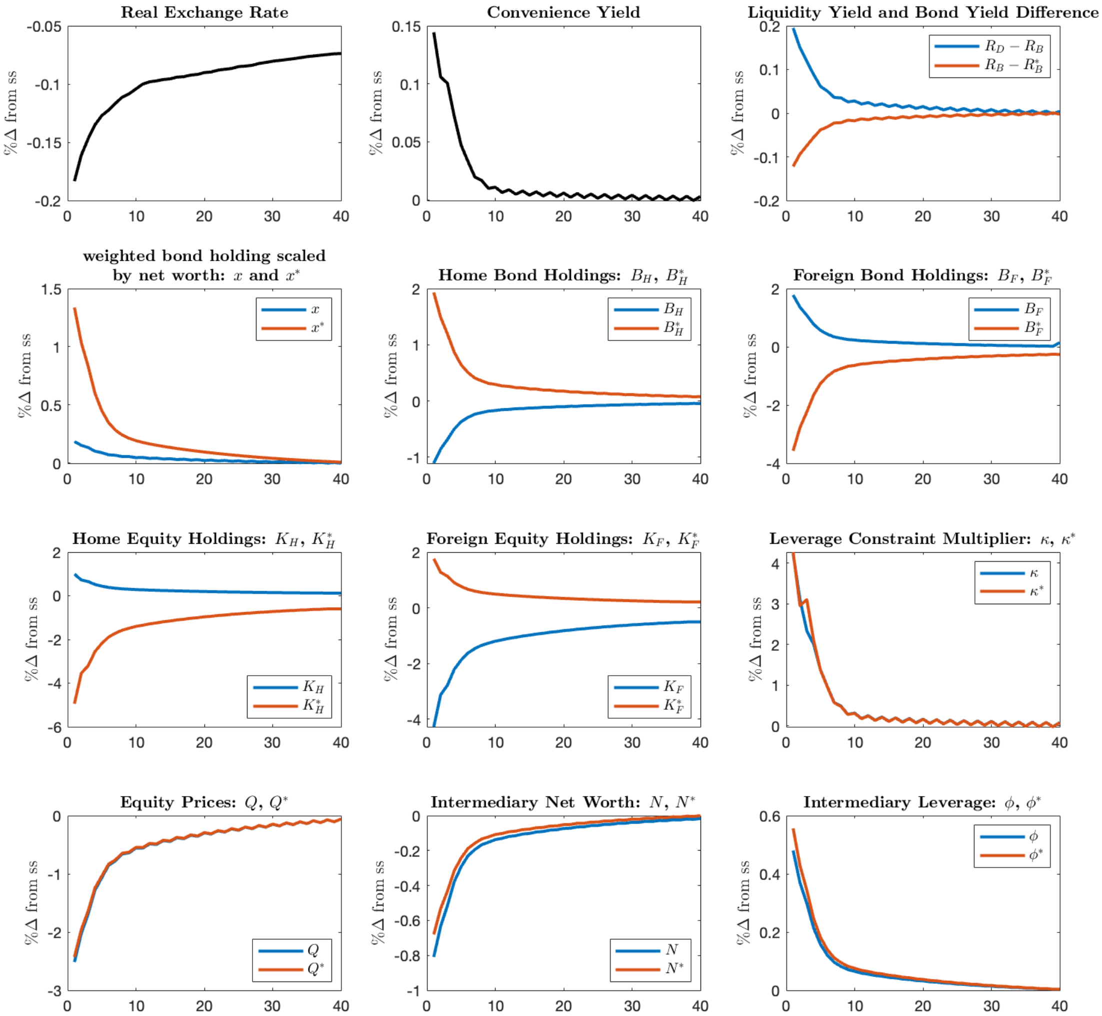


Figure 9: Impluse Response under an Endowment Shock

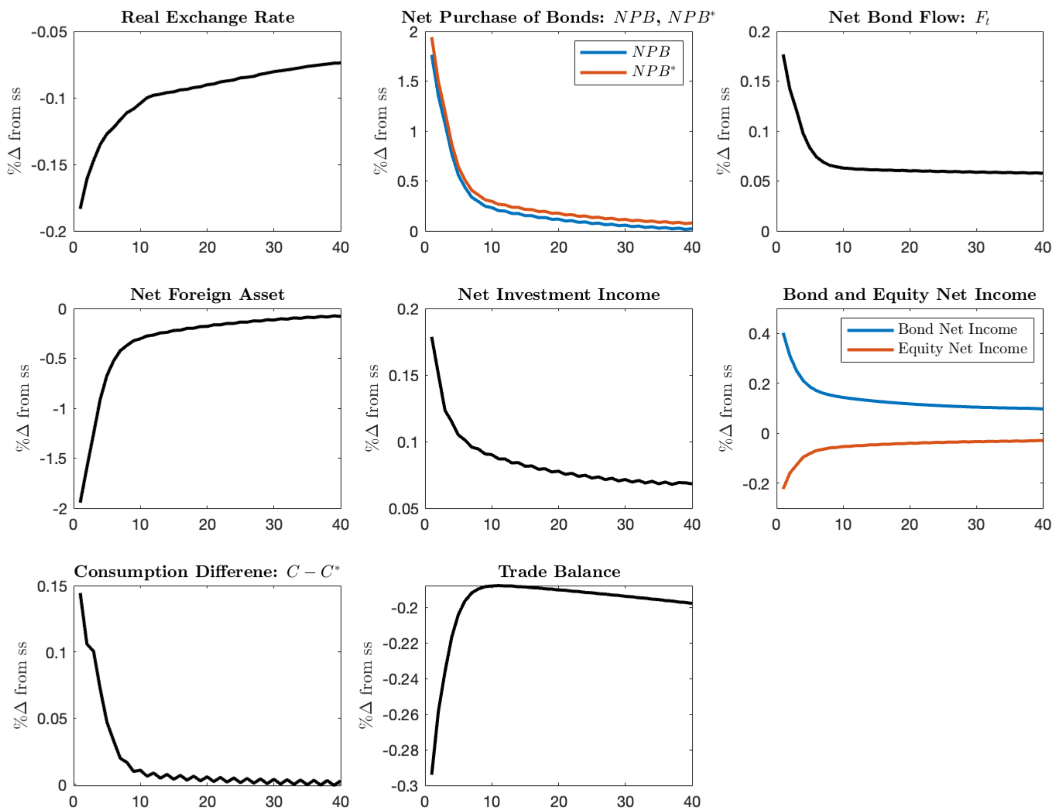


Figure 10: CIP Deviations under a Global Financial Shock

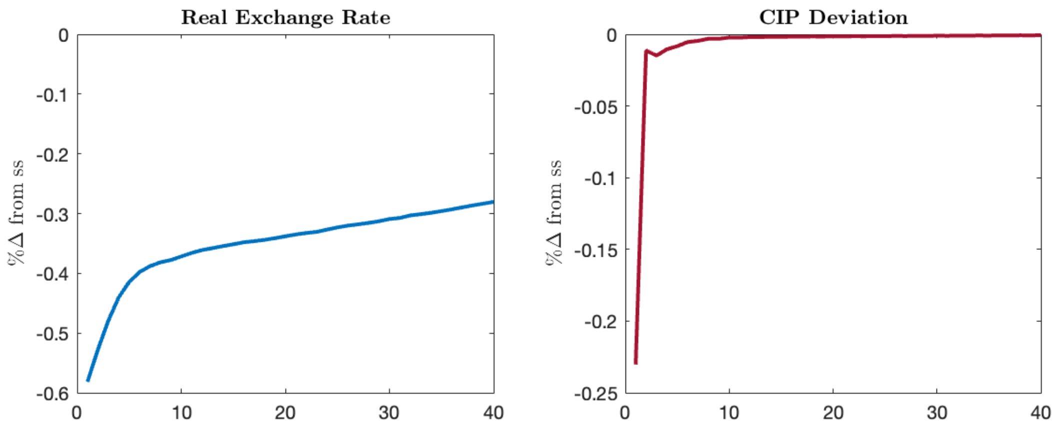


Table 1: Parameter Values

Parameter	Description	Value	Target
β	discount factor of home country	0.978	
β^*	discount factor of foreign country	0.9766	
α	home bias parameter	0.9	
γ	CRRA risk coefficient	3	
σ	survival rate of bankers	0.88	
$\bar{B}_G$	Home total government bond	0.027	Debt/GDP = 84%
$\bar{B}_G^*$	Foreign total government bond	0.027	
θ_0	baseline leverage tightness of Home	0.431	jointly targeting: Treasury basis of -0.0031
θ_0^*	baseline leverage tightness of Foreign	0.458	equity premium of 0.0102
ξ	Home start-up fund	0.0198	liquidity premium of 0.0028
ξ^*	Foreign start-up fund	0.0236	U.S. intermediary leverage of 3.678
ω_H	Home sensitivity to hold Home safe asset	0.119	holding of U.S. Treasury bond (B_H/B_H^*) of 1.902
ω_F	Home sensitivity to hold Foreign safe asset	0.031	Home intermedairy's home equity share of 0.729
ω_H^*	Foreign sensitivity to hold Home safe asset	0.199	Home NFA/GDP of -0.261
ω_F^*	Foreign sensitivity to hold Foreign safe asset	0.088	Home NII/GDP of 0.0089
ρ_Y	Home persistence of real shock	0.980	U.S. GDP
σ_Y	Home standard deviation of real shock	0.002	
ρ_Y^*	Foreign persistence of real shock	0.945	average of G10 country GDP
σ_Y^*	Foreign standard deviation of real shock	0.0056	
ρ_χ	persistence of financial shock	0.98	SMM to match the volatility of: exchange rate growth
σ_χ	standard deviation of financial shock	0.0055	Treasury basis, NFA and NII

Table 2: Steady State Values

Variables	Steady State Value	Variables	Steady State Value
C	0.0295	κ	0.0287
C^*	0.0290	κ^*	0.0361
R_B	1.0180	ϕ	3.567
R_B^*	1.0213	ϕ^*	3.262
R_D	1.0225	Trade balance (TB)	-0.0015
R_D^*	1.0239	Net investment income (NII)	0.0105
$R_K = R_K^*$	1.0332	Home bank's external equity share $\left(\frac{K_F}{K_F+B_F}\right)$	53.43%
NFA	-0.2492	Foreign bank's external equity share $\left(\frac{K_H^*}{K_H^*+B_H^*}\right)$	52.98%

Table 3: Simulation Results

Moments	Data	Benchmark Model	Real Shock Only
Standard Deviation			
$std(\Delta s)$	0.0431	0.0465	0.0122
$std(R_D - R_B)$	0.0047	0.0078	0.0032
$std(R_B - R_B^*)$	0.0097	0.0108	0.0020
$std(NFA/GDP)$	0.1075	0.1918	0.0194
$std(NII/GDP)$	0.0044	0.0098	0.0019
Correlation			
$corr(\Delta s, R_B - R_B^*)$	-0.1591	-0.1406	-0.1726
$corr(\Delta s, \Delta B_H^*)$	-0.3416	-0.7706	-0.1225
$corr(\Delta s, F)$	-0.3229	-0.5797	-0.1859
$corr(\Delta s, \Delta NII)$	-0.2929	-0.3779	-0.1961
$corr(\Delta B_H^*, \Delta NII)$	0.5116	0.3588	0.1830
$corr(\Delta s, \Delta c - \Delta c^*)$	-0.0479	0.1651	0.1114

Notes: Data moments are computed using either quarterly data or annually data from 2000Q1 to 2017Q4. Model implied moments are computed from a simulation of 10,000 quarter observations and burning the first 100 quarters.

A Equilibrium Conditions and Steady States

A.1 Equilibrium Conditions Characterization

In this appendix, I characterize all the equilibrium conditions of the model.

The competitive equilibrium is given by eleven price variables (S_t, $P_{H,t}, P_{F,t}, Q_t, Q_t^*$, $R_{K,t+1}$, $R^*_{K,t+1}, R_{B,t}, R^*_{B,t}, R_{D,t}, R^*_{D,t}$), eighteen quantity variables ($C_t, C_t^*, C_{H,t}, C^*_{H,t}, C_{F,,t}, C^*_{F,t}$, $B_{H,t}, B_{F,t}, B^*_{H,t}, B^*_{F,t}, K_{H,t}, K_{F,t}, K^*_{H,t}, K^*_{F,t}, N_t, N_t^*,$, T_t, T_t^*), twelve bank variables (μ_t, μ_t^*, κ_t, $\kappa_t^*, \psi_t, \psi_t^*, \phi_t, \phi_t^*, \theta_t, \theta_t^*, x_t, x_t^*$) and three exogenous shock process variables (Y_t, Y_t^*, χ_t).

Domestic and foreign household Euler equations:

$$E_t \left[\beta \left(\frac{C_{t+1}}{C_t} \right)^{-\gamma} R_{D,t} \right] = 1 \tag{A.1}$$

$$E_t \left[\beta \left(\frac{C^*_{t+1}}{C^*_t} \right)^{-\gamma} R^*_{D,t} \right] = 1 \tag{A.2}$$

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

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

$$C_t^* = \left(\frac{C^*_{H,t}}{1-\alpha} \right)^{(1-\alpha)} \left(\frac{C^*_{F,t}}{\alpha} \right)^{\alpha}$$

Solving the optimality condition, demand for home and foreign goods satisfy the following:

$$C_{H,t} = \frac{\alpha C_t}{P_{H,t}} \tag{A.3}$$

$$C_{F,t} = \frac{(1-\alpha) C_t}{P_{F,t}} \tag{A.4}$$

$$C^*_{H,t} = \frac{(1-\alpha) S_t C_t^*}{P_{H,t}} \tag{A.5}$$

$$C^*_{F,t} = \frac{\alpha S_t C_t^*}{P_{F,t}} \tag{A.6}$$

Real exchange rate can be solved as

$$S_t = \left(\frac{P_{F,t}}{P_{H,t}}\right)^{(2\alpha-1)} \tag{A.7}$$

Domestic and foreign return on capital:

$$R_{K,t+1} = \frac{Q_{t+1} + Y_{t+1}}{Q_t} \tag{A.8}$$

$$R^*_{K,t+1} = \frac{Q^*_{t+1} + Y^*_{t+1}}{Q^*_t} \tag{A.9}$$

Domestic and foreign aggregate financial intermedairy's net worth:

$$\begin{aligned} N_t =&\sigma[(R_{K,t} - R_{D,t-1})Q_{t-1}K_{H,t-1} + (\frac{S_t}{S_{t-1}}R^*_{K,t} - R_{D,t-1})Q^*_{t-1}K_{F,t-1}S_{t-1} \\ &+ (R_{B,t-1} - R_{D,t-1})B_{H,t-1} + (\frac{S_t}{S_{t-1}}R^*_{B,t-1} - R_{D,t-1})B_{F,t-1}S_{t-1} + R_{D,t-1}N_{t-1}] \\ &+ \xi(Q_{t-1}K_{H,t-1} + S_{t-1}Q^*_{t-1}K_{F,t-1}) \end{aligned} \tag{A.10}$$

$$\begin{aligned} N^*_t =&\sigma[(\frac{S_{t-1}}{S_t}R_{K,t} - R^*_{D,t-1})\frac{Q_{t-1}K^*_{H,t-1}}{S_{t-1}} + (R^*_{K,t} - R^*_{D,t-1})Q^*_{t-1}K^*_{F,t-1} \\ &+ (\frac{S_{t-1}}{S_t}R_{B,t-1} - R^*_{D,t-1})\frac{B^*_{H,t-1}}{S_{t-1}} + (R^*_{B,t-1} - R^*_{D,t-1})B^*_{F,t-1} + R^*_{D,t-1}N^*_{t-1}] \\ &+ \xi^*(\frac{1}{S_{t-1}}Q_{t-1}K^*_{H,t-1} + Q^*_{t-1}K^*_{F,t-1}) \end{aligned} \tag{A.11}$$

Domestic and foreign functional form of θ_t:

$$\theta_t = \theta_0\chi_t e^{-x_t} \tag{A.12}$$

$$\theta^*_t = \theta_0\chi_t e^{-x^*_t} \tag{A.13}$$

Domestic and foreign functional form of x_t:

$$x_t = \omega_H\left(\frac{B_{H,t}}{N_t}\right) + \omega_F\left(\frac{S_tB_{F,t}}{N_t}\right) \tag{A.14}$$

$$x^*_t = \omega^*_H\left(\frac{B^*_{H,t}/S_t}{N^*_t}\right) + \omega^*_F\left(\frac{B^*_{F,t}}{N^*_t}\right) \tag{A.15}$$

Relation between Lagrangian multiplier and financial intermediary leverage:

$$\phi_t = \frac{Q_t K_{H,t} + S_t Q_t^* K_{F,t}}{N_t} \tag{A.16}$$

$$\phi_t^* = \frac{Q_t K_{H,t}^* / S_t + Q_t^* K_{F,t}^*}{N_t^*} \tag{A.17}$$

Domestic and foreign intermediary marginal net worth ψ_t[13]

$$\psi_t = \frac{\mu_t}{1 - \kappa_t + \kappa_t x_t} \tag{A.18}$$

$$\psi_t^* = \frac{\mu_t^*}{1 - \kappa_t^* + \kappa_t^* x_t^*} \tag{A.19}$$

Relation between marginal net worth ψ_t and intermediate leverage ϕ_t:

$$\psi_t = \theta_t \phi_t \tag{A.20}$$

$$\psi_t^* = \theta_t^* \phi_t^* \tag{A.21}$$

Domestic and foreign financial intermediary stochastic discount factor:

$$\hat{M}_{t+1} = \beta \left(\frac{C_{t+1}}{C_t} \right)^{-\gamma} ((1 - \sigma) + \sigma \psi_{t+1})$$

$$\hat{M}_{t+1}^* = \beta \left(\frac{C_{t+1}^*}{C_t^*} \right)^{-\gamma} \left((1 - \sigma) + \sigma \psi_{t+1}^*\right)$$

Domestic and foreign Euler equations with deposits:

$$E_t[\hat{M}_{t+1} R_{D,t}] = \mu_t \tag{A.22}$$

$$E_t[\hat{M}_{t+1}^* R_{D,t}^*] = \mu_t^* \tag{A.23}$$

[13] Proof is shown in Appendix B.5.

Domestic and foreign Euler equations with domestic capital:

$$E_t\left[\hat{M}_{t+1}R_{K,t+1}\right] = \mu_t + \kappa_t\theta_t \tag{A.24}$$

$$E_t\left[\hat{M}^*_{t+1}\frac{S_t}{S_{t+1}}R_{K,t+1}\right] = \mu^*_t + \kappa^*_t\theta^*_t \tag{A.25}$$

Domestic and foreign Euler equations with foreign capital:

$$E_t\left[\hat{M}_{t+1}\frac{S_{t+1}}{S_t}R^*_{K,t+1}\right] = \mu_t + \kappa_t\theta_t \tag{A.26}$$

$$E_t\left[\hat{M}^*_{t+1}R^*_{K,t+1}\right] = \mu^*_t + \kappa^*_t\theta_t \tag{A.27}$$

Domestic and foreign Euler equations with domestic government bond:

$$E_t\left[\hat{M}_{t+1}R_{B,t}\right] = \mu_t - \omega_H\kappa_t\theta_t\phi_t \tag{A.28}$$

$$E_t\left[\hat{M}^*_{t+1}\frac{S_t}{S_{t+1}}R_{B,t}\right] = \mu^*_t - \omega^*_H\kappa^*_t\theta^*_t\phi^*_t \tag{A.29}$$

Domestic and foreign Euler equations with foreign government bond:

$$E_t\left[\hat{M}_{t+1}\frac{S_{t+1}}{S_t}R^*_{B,t}\right] = \mu_t - \omega_F\kappa_t\theta_t\phi_t \tag{A.30}$$

$$E_t\left[\hat{M}^*_{t+1}R^*_{B,t}\right] = \mu^*_t - \omega^*_F\kappa^*_t\theta^*_t\phi^*_t \tag{A.31}$$

Domestic and foreign government budget constraint:

$$T_t = (R_{B,t-1} - 1)\bar{B}_G \tag{A.32}$$

$$T^*_t = (R^*_{B,t-1} - 1)\bar{B}^*_G \tag{A.33}$$

Domestic and foreign capital market clear:

$$K_{H,t} + K^*_{H,t} = 1 \tag{A.34}$$

$$K_{F,t} + K^*_{F,t} = 1 \tag{A.35}$$

Domestic and foreign government bond market clear:

$$B_{H,t} + B^*_{H,t} = \bar{B}_G \tag{A.36}$$

$$B_{F,t} + B^*_{F,t} = \bar{B}^*_G \tag{A.37}$$

Domestic and foreign consumption good market clearing:

$$C_{H,t} + C^*_{H,t} = Y_t \tag{A.38}$$

$$C_{F,t} + C^*_{F,t} = Y^*_t \tag{A.39}$$

Domestic and foreign aggregate budget constraint for households and intermediaries:

$$\begin{aligned} C_t + Q_t K_{H,t} + S_t Q^*_t K_{F,t} + B_{H,t} + S_t B_{F,t} = {} & R_{K,t} Q_{t-1} K_{H,t-1} + S_t R^*_{K,t} Q^*_{t-1} K_{F,t-1} \\ & + R_{B,t-1} B_{H,t-1} + S_t R^*_{B,t-1} B_{F,t-1} - T_t \end{aligned} \tag{A.40}$$

$$\begin{aligned} C^*_t + \frac{1}{S_t} Q_t K^*_{H,t} + Q^*_t K^*_{F,t} + \frac{1}{S_t} B^*_{H,t} + B^*_{F,t} = {} & \frac{1}{S_t} R_{K,t} Q_{t-1} K^*_{H,t-1} + R^*_{K,t} Q^*_{t-1} K^*_{F,t-1} \\ & + \frac{1}{S_t} R_{B,t-1} B^*_{H,t-1} + R^*_{B,t-1} B^*_{F,t-1} - T^*_t \end{aligned} \tag{A.41}$$

Exogenous shock process:

$$\log(Y_t/\bar{Y}) = \rho_Y \log(Y_{t-1}/\bar{Y}) + \sigma_Y \varepsilon_{Y,t} \tag{A.42}$$

$$\log(Y^*_t/\bar{Y}^*) = \rho_Y \log(Y^*_{t-1}/\bar{Y}^*) + \sigma_Y \varepsilon_{Y,t} \tag{A.43}$$

$$\log(\chi_t) = \rho_\chi \log(\chi_{t-1}) + \sigma_\chi \varepsilon_{\chi,t} \tag{A.44}$$

A.2 Solving Steady States

Start from Euler equations of the households, in steady state, we have that:

$$M = \beta \quad \text{and} \quad R_D = \frac{1}{\beta}$$

$$M^* = \beta^* \quad \text{and} \quad R_D^* = \frac{1}{\beta^*}$$

Steady state equity prices are 1: $Q = Q^* = 1$.

Return from equity is the same for both countries, we have that

$$R_K = R_K^* = \frac{\bar{Y} + 1}{1} = 1 + \bar{Y}$$

Financial intermediary's SDF:

$$\hat{M} = M(1 - \sigma + \sigma\psi) = \beta(1 - \sigma + \sigma\theta\phi)$$

$$\hat{M}^* = M^*(1 - \sigma + \sigma\psi) = \beta^*(1 - \sigma + \sigma\theta^*\phi^*)$$

From Euler equations with respect to deposits, we can solve for steady state μ and μ^* as

$$\mu = \hat{M}\frac{1}{\beta} = 1 - \sigma + \sigma\theta\phi$$

$$\mu^* = \hat{M}^*\frac{1}{\beta^*} = 1 - \sigma + \sigma\theta^*\phi^*$$

Following (Gertler & Karadi, 2011), let steady state value of θ_t and θ_t^* be 0.381.

$$\theta = 0.381 \quad \text{and} \quad \theta^* = 0.381$$

Given parameter $\theta_0 = 0.431$ and $\theta_0^* = 0.458$, we can solve for steady state x_t and x_t^* as:

$$x = \log(\theta_0/\theta) = \log(0.431/0.381) = 0.0198$$

$$x^* = \log(\theta_0^*/\theta^*) = \log(0.458/0.381) = 0.0237$$

In steady state, we have that

$$\psi = \theta\phi = \frac{\mu}{1-\kappa+\kappa x} = \frac{1-\sigma+\sigma\theta\phi}{1-\kappa+\kappa x}$$

$$\psi^* = \theta^*\phi^* = \frac{\mu^*}{1-\kappa^*+\kappa^* x^*} = \frac{1-\sigma+\sigma\theta^*\phi^*}{1-\kappa^*+\kappa^* x^*}$$

From the above equations, we can derive

$$\theta\phi(1-\kappa+\kappa x) = 1-\sigma+\sigma\theta\phi$$

$$\theta\phi - \theta\phi\kappa + \theta\phi\kappa x = 1-\sigma+\sigma\theta\phi$$

Plug in financial intermediary's Euler equation with respect to equity

$$\beta(1-\sigma+\sigma\theta\phi)(R_K-R_D) = \theta\kappa$$

we can get

$$\phi[(1-\sigma)\theta - \beta(1-\sigma+\sigma\theta\phi)(R_K-R_D)(1-x)] = 1-\sigma$$

This is considered as a second order equation of ϕ:

$$\phi^2\beta\sigma\theta(R_K-R_D)(1-x) - \phi[\theta-\beta(1-x)(R_K-R_D)](1-\sigma) + 1-\sigma = 0$$

with

$$aa = \beta\sigma\theta(R_K-R_D)(1-x)$$

$$bb = -[\theta-\beta(1-x)(R_K-R_D)](1-\sigma)$$

$$cc = 1-\sigma$$

Thus, we can solve for ϕ as

$$\phi = \frac{-bb - \sqrt{bb^2 - 4aa * cc}}{2aa} \quad \text{(The lower leverage)}$$

Following the similar steps, we can solve for foreign leverage ϕ^*

$$\phi^{*2}\beta^*\sigma\theta^*(R_K^* - R_D^*)(1 - x^*) - \phi^*[\theta^* - \beta^*(1 - x^*)(R_K^* - R_D^*)](1 - \sigma) + 1 - \sigma = 0$$

with

$$aa^* = \beta^*\sigma\theta^*(R_K^* - R_D^*)(1 - x^*)$$

$$bb^* = -[\theta^* - \beta^*(1 - x^*)(R_K^* - R_D^*)](1 - \sigma)$$

$$cc^* = 1 - \sigma$$

ϕ^* can be solved as

$$\phi^* = \frac{-bb^* - \sqrt{bb^{*2} - 4aa^* * cc^*}}{2aa^*} \quad \text{(The lower leverage)}$$

We can solve for ψ and ψ^* when steady state leverages are solved:

$$\psi = \theta\phi$$

$$\psi^* = \theta^*\phi^*$$

From model equilibrium equation (A.10) and (A.11), we can solve for steady state N and N^*

$$N = \sigma[(R_K - R_D)\frac{K_H}{N} + (R_K^* - R_D)\frac{SK_F}{N} + (R_B - R_D)\frac{B_H}{N} + (R_B^* - R_D)\frac{SB_F}{N} + R_D]N + \xi(K_H + SK_F)$$

$$N = \sigma\left[\frac{\theta\kappa}{\hat{M}}\left(\frac{K_H + SK_F}{N}\right) - \frac{\theta\kappa\phi}{\hat{M}}\left(\omega_H\frac{B_H}{N} + \omega_F\frac{SB_F}{N}\right) + R_D\right]N + \xi(K_H + SK_F)$$

$$N = \sigma[(R_K - R_D)\phi - (R_K - R_D)\phi x + R_D]N + \xi(K_H + SK_F)$$

Steady state N can be solved as

$$N = \frac{\xi(K_H + SK_F)}{1 - \sigma[(R_K - R_D)\phi(1-x) + R_D]}$$

Similarly, N^* can be solved as

$$N^* = \frac{\xi(K_H^* + SK_F^*)}{1 - \sigma[(R_K^* - R_D^*)\phi^*(1-x^*) + R_D^*]}$$

Once N is solved, we can solve for Π:

$$\Pi + N = [(R_K - R_D)\phi(1-x) + R_D]N$$

$$\Pi = [(R_K - R_D)\phi(1-x) + R_D - 1]N$$

Similarly,

$$\Pi^* = [(R_K^* - R_D^*)\phi^*(1-x^*) + R_D^* - 1]N^*$$

We can solve for steady state κ and κ^* from financial intermediary's Euler equation with respect to equity

$$\beta((1-\sigma) + \sigma\psi)(1+\bar{Y}) = \mu + \kappa\theta$$

$$\kappa = \frac{\beta((1-\sigma) + \sigma\psi)(1+\bar{Y}) - (1-\sigma+\sigma\psi)}{\theta}$$

Similarly

$$\kappa^* = \frac{\beta^*((1-\sigma) + \sigma\psi^*)(1+\bar{Y}^*) - (1-\sigma+\sigma\psi^*)}{\theta^*}$$

R_B and R_B^* can be solved from the Euler equation with respect to government bond

$$R_B = \frac{\mu - \omega_H\kappa\psi}{\hat{M}} = \frac{(1-\sigma+\sigma\psi) - \omega_H\kappa\psi}{\beta(1-\sigma+\sigma\psi)}$$

$$R_B = \frac{\mu^* - \omega_H^*\kappa^*\psi^*}{\hat{M}^*} = \frac{(1-\sigma+\sigma\psi^*) - \omega_H^*\kappa^*\psi^*}{\beta^*(1-\sigma+\sigma\psi^*)}$$

$$R_B^* = \frac{\mu^* - \omega_F^*\kappa^*\psi^*}{\hat{M}^*} = \frac{(1-\sigma+\sigma\psi^*) - \omega_F^*\kappa^*\psi^*}{\beta^*(1-\sigma+\sigma\psi^*)}$$

$$R_B^* = \frac{\mu - \omega_F \kappa \psi}{\hat{M}} = \frac{(1-\sigma+\sigma\psi) - \omega_F \kappa \psi}{\beta(1-\sigma+\sigma\psi)}$$

Steady state tax T and T^* can be solved as

$$T = (R_B - 1)\bar{B}_G$$

$$T^* = (R_B^* - 1)\bar{B}_G^*$$

Combining equation (A.14), (A.15), (A.36) and (A.37) to solve for B_H, B_F, B_H^*, and B_F^*.

$$x = \frac{\omega_H B_H + S\omega_F B_F}{N}$$

$$x^* = \frac{\omega_H^* B_H^*/S + \omega_F^* B_F^*}{N^*}$$

$$B_H + B_H^* = \bar{B}_G$$

$$B_F + B_F^* = \bar{B}_G^*$$

Substitute out B_H^* and B_F^*, plug in

$$B_F = \frac{xN - \omega_H B_H}{\omega_F S}$$

$$\omega_H^*(\bar{B}_G - B_H)/S + \omega_F^*\left(\bar{B}_G^* - \frac{xN - \omega_H B_H}{\omega_F S}\right) = x^* N$$

Combining terms, we can solve for B_H:

$$B_H = \left[x^* N^* - \frac{\omega_H^* \bar{B}_G}{S} - \omega_F^* \bar{B}_G^* + \frac{\omega_F^* x N}{\omega_F S}\right] \frac{\omega_F S}{\omega_F^* \omega_H - \omega_H^* \omega_F}$$

Once, we solved for B_H, it's easy to get B_F, B_H^* and B_F^*.

$$B_F = \frac{xN - \omega_H B_H}{\omega_F S}$$

$$B_H^* = \bar{B}_G - B_H$$

$$B_F^* = \bar{B}_G^* - B_F$$

Steady state consumption C and C^* can be solved using equation (A.40) and (A.41)

$$C = R_K K_H + S R_K^* K_F + R_B B_H + S R_B^* B_F - T - K_H - S K_F - B_H - S B_F$$

$$C^* = \frac{1}{S} R_K K_H^* + R_K^* K_F^* + \frac{1}{S} R_B B_H^* + R_B^* B_F^* - T^* - \frac{1}{S} K_H^* - K_F^* - \frac{1}{S} B_H^* - B_F^*$$

B Derivation and Proofs

B.1 Proof of Proposition 1

Giving Cobb-Douglas aggregate consumption, domestic household faces the following problem:

$$\max E_t \sum_{k=0}^{\infty} \beta^k \left[\frac{\left(\left(\frac{C_{H,t+k}}{\alpha} \right)^{\alpha} \left(\frac{C_{F,t+k}}{1-\alpha} \right)^{(1-\alpha)} \right)^{1-\gamma} - 1}{1-\gamma} \right]$$

$$s.t. \quad P_{H,t} C_{H,t} + P_{F,t} C_{F,t} + D_t = R_{D,t-1} D_{t-1} + \Pi_t - T_t$$

FOC w.r.t. D_t:

$$C_t^{-\gamma} = \beta E_t [C_{t+1}^{-\gamma} R_{D,t}] \tag{B.1}$$

FOC w.r.t. $C_{H,t}$:

$$C_t^{-\gamma} \left(\frac{C_{H,t}}{\alpha} \right)^{\alpha-1} \left(\frac{C_{F,t}}{1-\alpha} \right)^{1-\alpha} = \lambda_t P_{H,t} \tag{B.2}$$

FOC w.r.t. $C_{F,t}$:

$$C_t^{-\gamma} \left(\frac{C_{H,t}}{\alpha} \right)^{\alpha} \left(\frac{C_{F,t}}{1-\alpha} \right)^{-\alpha} = \lambda_t P_{F,t} \tag{B.3}$$

Take the ratio of eqation (B.2) and (B.3):

$$\frac{C_{F,t}}{C_{H,t}} = \frac{P_{H,t}}{P_{F,t}} \frac{1-\alpha}{\alpha} \tag{B.4}$$

Similarly, for the foreign country, we can get

$$\frac{C^*_{F,t}}{C^*_{H,t}} = \frac{P_{H,t}}{P_{F,t}} \frac{\alpha}{1-\alpha} \tag{B.5}$$

Plug in equation (B.4) and (B.5) into the following two equations:

$$P_{H,t}C_{H,t} + P_{F,t}C_{F,t} = C_t \tag{B.6}$$

$$P_{H,t}C^*_{H,t} + P_{F,t}C^*_{F,t} = S_tC^*_t \tag{B.7}$$

We can solve for the following:

$$C_{H,t} = \frac{\alpha C_t}{P_{H,t}} \tag{B.8}$$

$$C_{F,t} = \frac{(1-\alpha)C_t}{P_{F,t}} \tag{B.9}$$

$$C^*_{H,t} = \frac{(1-\alpha)S_tC^*_t}{P_{H,t}} \tag{B.10}$$

$$C^*_{F,t} = \frac{\alpha S_tC^*_t}{P_{F,t}} \tag{B.11}$$

Plug in equation (B.8) and (B.9) into $C_t = \left(\frac{C_{H,t}}{\alpha}\right)^{\alpha} \left(\frac{C_{F,t}}{1-\alpha}\right)^{(1-\alpha)}$:

$$C_t = \left(\frac{\alpha C_t}{\alpha P_{H,t}}\right)^{\alpha} \left(\frac{(1-\alpha)C_t}{(1-\alpha)P_{F,t}}\right)^{1-\alpha} \tag{B.12}$$

After cancelling out terms, it implies that

$$P^{\alpha}_{H,t}P^{1-\alpha}_{F,t} = 1 \tag{B.13}$$

Similarly, plug in equation (B.10) and (B.11) into $C^*_t = \left(\frac{C^*_{H,t}}{1-\alpha}\right)^{(1-\alpha)} \left(\frac{C^*_{F,t}}{\alpha}\right)^{\alpha}$:

$$C^*_t = \left(\frac{(1-\alpha)S_tC^*_t}{(1-\alpha)P_{H,t}}\right)^{(1-\alpha)} \left(\frac{\alpha S_tC^*_t}{\alpha P_{F,t}}\right)^{\alpha} \tag{B.14}$$

After cancelling out terms, we can get

$$\frac{S_t}{P_{H,t}^{1-\alpha} P_{F,t}^{\alpha}} = 1 \tag{B.15}$$

Combining equation (B.13) and (B.15) gives

$$S_t = \left(\frac{P_{F,t}}{P_{H,t}} \right)^{2\alpha - 1} \tag{B.16}$$

B.2 Proof of Lemma 1

If there is liquidity yield $R_{D,t} - R_{B,t} > 0$, then the home financial intermediary must bind. Suppose not. If there is one optimal home financial intermedairy's portfolio to be $(B_{H,t}, B_{F,t}, K_{H,t}, K_{F,t}, D_t)$, then consider an alternative portfolio $(B_{H,t} - \varepsilon, B_{F,t}, K_{H,t}, K_{F,t}, D_t - \varepsilon)$. We can find ε small enough so that the leverage constaint still does not bind. This new portfolio would satisfy the balance sheet constraint of the intermediary

$$Q_t K_{H,t+1} + S_t Q_t^* K_{F,t+1} + (B_{H,t} - \varepsilon) + S_t B_{F,t} = N_t + (D_t - \varepsilon)$$

and earn a higher return such that

$$\begin{aligned} N'_{t+1} &= R_{K+1} Q_t K_{H,t+1} + S_{t+1} R^*_{K,t+1} Q_t^* K_{F,t+1} + R_{B,t}(B_{H,t} - \varepsilon) + S_{t+1} R^*_{B,t} B_{F,t} - R_{D,t}(D_t - \varepsilon) \\ &= N_{t+1} + (R_{D,t} - R_{B,t})\varepsilon \end{aligned}$$

Since we know that $R_{D,t} - R_{B,t} > 0$, it a constradiction that the original portfolio is the financial interemdairy's optimal choice. Therefore, the home intermediary's leverage constraint binds. Similarly, since we observe in the data that $R^*_{D,t} - R^*_{B,t} > 0$, following the same steps, we can show that foreign intermediary's leverage constraint also binds.

B.3 Proof of Lemma 2

Lemma 2 can be proved using the guess and verify method. First, we write out the home individual financial intermediary's problem as

$$V(N_{i,t}) = \max_{K_{H,i,t},K_{F,i,t},B_{H,i,t},B_{F,i,t},D_{i,t}} E_t\left[M_{t+1}((1-\sigma)N_{i,t+1} + \sigma V(N_{i,t+1}))\right] \tag{B.17}$$

such that

$$N_{i,t+1} = R_{K,t+1}Q_tK_{H,i,t} + S_{t+1}R^*_{K,t+1}Q^*_tK_{F,i,t} + R_{B,t}B_{H,i,t} + S_{t+1}R^*_{B,t}B_{F,i,t} - R_{D,t}D_{i,t} \tag{B.18}$$

$$Q_tK_{H,i,t} + S_tQ^*_tK_{F,i,t} + B_{H,i,t} + S_tB_{F,i,t} = N_{i,t} + D_{i,t} \tag{B.19}$$

$$V(N_{i,t}) \geq \theta_0\chi_t \exp\left(-\left(\omega_H\frac{B_{H,i,t}}{N_{i,t}} + \omega_F\frac{S_tB_{F,i,t}}{N_{i,t}}\right)\right)(Q_tK_{H,i,t} + Q^*_tS_tK_{F,i,t}) \tag{B.20}$$

Take (B.18) into (B.17), we can get the problem transformed as

$$\begin{aligned} V(N_{i,t}) = \max_{K_{H,i,t},K_{F,i,t},B_{H,i,t},B_{F,i,t},D_{i,t}} & E_t[M_{t+1}((1-\sigma)(R_{K,t+1}Q_tK_{H,i,t} + S_{t+1}R^*_{K,t+1}Q^*_tK_{F,i,t} \\ & + R_{B,t}B_{H,i,t} + S_{t+1}R^*_{B,t}B_{F,i,t} - R_{D,t}D_{i,t}) + \sigma V(N_{i,t+1}))] \end{aligned} \tag{B.21}$$

Let the Lagrange multiplier on (B.19) be μ_t and the multiplier on (B.20) be κ_t. Take first order conditions, we can get

$$E_t\left[M_{t+1}(1-\sigma+\sigma V'(N_{i,t+1}))R_{K,t+1}\right] = \mu_t + \kappa_t\theta_0\chi_t \exp\left(-\left(\omega_H\frac{B_{H,i,t}}{N_{i,t}} + \omega_F\frac{S_tB_{F,i,t}}{N_{i,t}}\right)\right) \tag{B.22}$$

$$E_t\left[M_{t+1}(1-\sigma+\sigma V'(N_{i,t+1}))\frac{S_{t+1}}{S_t}R^*_{K,t+1}\right] = \mu_t + \kappa_t\theta_0\chi_t \exp\left(-\left(\omega_H\frac{B_{H,i,t}}{N_{i,t}} + \omega_F\frac{S_tB_{F,i,t}}{N_{i,t}}\right)\right) \tag{B.23}$$

$$\begin{aligned} E_t[M_{t+1}(1-\sigma+\sigma V'(N_{i,t+1}))R_{B,t}] = \mu_t - \kappa_t\omega_H\theta_0\chi_t & \exp\left(-\left(\omega_H\frac{B_{H,i,t}}{N_{i,t}} + \omega_F\frac{S_tB_{F,i,t}}{N_{i,t}}\right)\right) \\ & (Q_tK_{H,i,t} + Q^*_tS_tK_{F,i,t})\left(\frac{1}{N_{i,t}}\right) \end{aligned} \tag{B.24}$$

$$E_t\left[M_{t+1}(1-\sigma+\sigma V'(N_{i,t+1}))\frac{S_{t+1}}{S_t}R^*_{B,t}\right]=\mu_t-\kappa_t\omega_F\theta_0\chi_t\exp\left(-\left(\omega_H\frac{B_{H,i,t}}{N_{i,t}}+\omega_F\frac{S_tB_{F,i,t}}{N_{i,t}}\right)\right)$$
$$(Q_tK_{H,i,t}+Q^*_tS_tK_{F,i,t})\left(\frac{1}{N_{i,t}}\right) \tag{B.25}$$

$$E_t[M_{t+1}(1-\sigma+\sigma V'(N_{i,t+1}))R_{D,t}]=\mu_t \tag{B.26}$$

The solution of the recursive system is a set of choice variables $K_{H,i,t}, K_{F,i,t}, B_{H,i,t}, B_{F,i,t}, D_{i,t}$ and multipliers μ_t, κ_t under the endogenous state $N_{i,t}$ and exogenous state t satisfying (B.19), (B.20), (B.22), (B.23), (B.24), (B.25) and (B.26).

Guess the value function

$$V(N_{i,t})=\psi_tN_{i,t}$$

And the policy functions are also linear in net worth such that $K_{H,i,t}(N_{i,t})=\tilde{K}_HN_{i,t}$, $K_{F,i,t}(N_{i,t})=\tilde{K}_FN_{i,t}$, $B_{H,i,t}(N_{i,t})=\tilde{B}_HN_{i,t}$, $B_{F,i,t}(N_{i,t})=\tilde{B}_FN_{i,t}$, $D_{i,t}(N_{i,t})=\tilde{D}N_{i,t}$, and the multipliers $\mu_{i,t}(N_{i,t})=\tilde{\mu}N_{i,t}$ and $\kappa_{i,t}(N_{i,t})=\tilde{\kappa}N_{i,t}$. In order to verify the guess, I need to show the system has to hold for every state $N_{i,t}$. Plug in the guess to the system, equation (B.19) becomes

$$Q_t\tilde{K}_H+S_tQ^*_t\tilde{K}_F+\tilde{B}_H+S_t\tilde{B}_F=1+\tilde{D}$$

(B.20) becomes

$$\phi_t\geq\chi_t\theta_0\exp(-(\omega_H\tilde{B}_H+S_t\omega_F\tilde{B}_F))(Q_t\tilde{K}_H+S_tQ^*_t\tilde{K}_F)$$

(B.22) becomes

$$E_t\left[M_{t+1}(1-\sigma+\sigma\psi_{t+1})R_{K,t+1}\right]=\tilde{\mu}+\tilde{\kappa}\theta_0\chi_t\exp(-(\omega_H\tilde{B}_H+S_t\omega_F\tilde{B}_F))$$

(B.23) becomes

$$E_t\left[M_{t+1}(1-\sigma+\sigma\psi_{t+1})\frac{S_{t+1}}{S_t}R_{K,t+1}\right]=\tilde{\mu}+\tilde{\kappa}\theta_0\chi_t\exp(-(\omega_H\tilde{B}_H+S_t\omega_F\tilde{B}_F))$$

(B.24) becomes

$$E_t[M_{t+1}(1-\sigma+\sigma\psi_{t+1})R_{B,t}] = \tilde{\mu} - \tilde{\kappa}\omega_F\theta_0\chi_t \exp(-(\omega_H\tilde{B}_H + S_t\omega_F\tilde{B}_F))(Q_t\tilde{K}_H + S_tQ_t^*\tilde{K}_F)$$

(B.25) becomes

$$E_t[M_{t+1}(1-\sigma+\sigma\psi_{t+1})R_{B,t}] = \tilde{\mu} - \tilde{\kappa}\omega_F\theta_0\chi_t \exp(-(\omega_F\tilde{B}_H + S_t\omega_F\tilde{B}_F))(Q_t\tilde{K}_H + S_tQ_t^*\tilde{K}_F)$$

(B.26) becomes

$$E_t[M_{t+1}(1-\sigma+\sigma\psi_{t+1})R_{D,t}] = \tilde{\mu}$$

We can see that none of these equations is dependent on the state $N_{i,t}$, so the guess is correct. For the foreign country, the proof can follow the same steps. Then, it is trivial to show that financial intermediaries are homogenous and behave exactly the same in equilibrium. All of them face the same optimality probem and the exact same balance sheet constraint and leverage constraint. This completes the proof.

B.4 Proof of Proposition 2

The risk premium can be derived using (B.22) - (B.26):

$$E_t[\hat{M}_{t+1}(R_{K,t+1} - R_{D,t})] = \kappa_t\theta_t$$

Since I have shown that financial intermedairy's leverage constraint always binds, equation (B.20) can be rewritten as

$$\psi_t = \theta_0\chi_t \exp\left(-\left(\omega_H\frac{B_{H,i,t}}{N_{i,t}} + \omega_F\frac{S_tB_{F,i,t}}{N_{i,t}}\right)\right)\left(\frac{Q_tK_{H,i,t} + Q_t^*S_tK_{F,i,t}}{N_{i,t}}\right)$$

By definition that intermediary's leverage is $\phi_t = \left(\frac{Q_tK_{H,i,t}+Q_t^*S_tK_{F,i,t}}{N_{i,t}}\right)$, we have that

$$\psi_t = \theta_t\phi_t$$

Using (B.26) minus (B.24), we can obtain the liquidity premium as

$$E_t[\hat{M}_{t+1}(R_{D,t} - R_{B,t})] = \omega_H \kappa_t \theta_t \phi_t$$

Using (B.26) minus (B.25), we can get

$$E_t\left[\hat{M}_{t+1}\left(R_{D,t} - \frac{S_{t+1}}{S_t} R^*_{B,t}\right)\right] = \omega_F \kappa_t \theta_t \phi_t$$

Assume that financial intermediary's SDF and returns on government bonds are conditionally log normal.

$$E_t[\hat{M}_{t+1} R_{B,t}] = \lambda_t - \omega_H \kappa_t \theta_t \phi_t$$

We can rewrite the above equation as

$$E_t\left[e^{\log \hat{M}_{t+1} R_{B,t}}\right] = \lambda_t - \omega_H \kappa_t \theta_t \phi_{H,t} \tag{B.27}$$

Let $\hat{m}_{t+1}$ be the log SDF of the doemstic financial intermediary and $r_{B,t}$ be the log return on doemstic government bond. Equation (B.27) can be rewritten as

$$E_t[\hat{m}_{t+1}] + r_{B,t} + \frac{1}{2} Var_t(\hat{m}_{t+1}) = \log(\lambda_t - \omega_H \kappa_t \theta_t \phi_t) \tag{B.28}$$

Similarly, for foreign government bond, I assume that financial intermediary's SDF, change of exchange rate and return on government bond are conditionally lognormal.

$$E_t\left[e^{\hat{m}_{t+1} + \Delta s_{t+1} + r^*_{B,t+1}}\right] = \lambda_t - \omega_F \kappa_t \theta_t \phi_t$$

$$\begin{aligned} E_t[\hat{m}_{t+1}] + E_t[\Delta s_{t+1}] + r^*_{B,t} + \frac{1}{2} Var_t(\hat{m}_{t+1}) + \frac{1}{2} Var_t(\Delta s_{t+1}) + Cov_t(\hat{m}_{t+1}, \Delta s_{t+1}) \\ = \log(\lambda_t - \omega_F \kappa_t \theta_t \phi_t) \end{aligned} \tag{B.29}$$

Then, UIP condition can be derived as equation (B.29) minus (B.28):

$$
\begin{aligned}
E_t[\Delta s_{t+1}] + r^*_{B,t} - r_{B,t} = & \underbrace{-Cov_t(\hat{m}_{H,t+1}, \Delta s_{t+1}) - \frac{1}{2}Var_t(\Delta s_{t+1})}_{\text{risk premium adjusted by the Jensen term}} \\
& + \underbrace{\log(\mu_t - \omega_F \kappa_t \theta_t \phi_t) - \log(\mu_t - \omega_H \kappa_t \theta_t \phi_t)}_{\text{relative convenience yield gap}}
\end{aligned} \tag{B.30}
$$

B.5 Proof of Equation of Intermediary Marginal Net Worth

Financial intermediary's problem

$$
V(N_t) = \max E_t[\hat{M}_{t+1} N_{t+1}]
$$

which can be rewritten as

$$
\psi_t = \max E_t \left[\hat{M}_{t+1} \frac{N_{t+1}}{N_t} \right]
$$

$$
s.t. \quad \psi_t \geq \theta_t \phi_t
$$

$$
\begin{aligned}
\frac{N_{t+1}}{N_t} = & (R_{K,t+1} - R_{D,t}) \frac{Q_t K_{H,t}}{N_t} + \left(\frac{S_{t+1}}{S_t} R^*_{K,t+1} - R_{D,t} \right) \frac{S_t Q^*_t K_{F,t}}{N_t} \\
& + (R_{B,t} - R_{D,t}) \frac{B_{H,t}}{N_t} + \left(\frac{S_{t+1}}{S_t} R^*_{B,t} - R_{D,t} \right) \frac{S_t B_{F,t}}{N_t} + R_{D,t}
\end{aligned}
$$

Plug in the FOCs from the financial intermediary's problem, then we can get

$$
\psi_t = \theta_t \kappa_t \frac{Q_t K_{H,t}}{N_t} + \theta_t \kappa_t \frac{S_t Q^*_t K_{F,t}}{N_t} - \omega_H \kappa_t \psi_t \frac{B_{H,t}}{N_t} - \omega_F \kappa_t \psi_t \frac{S_t B_{F,t}}{N_t} + \mu_t
$$

$$
\psi_t = \theta_t \kappa_t \left(\frac{Q_t K_{H,t} + S_t Q^*_t K_{F,t}}{N_t} \right) - \kappa_t \psi_t \left(\frac{\omega_H B_{H,t} + \omega_F S_t B_{F,t}}{N_t} \right) + \mu_t
$$

$$
\psi_t = \theta_t \kappa_t \phi_t - \kappa_t \psi_t x_t + \mu_t
$$

Since $\psi_t = \theta_t \phi_t$, it implies that

$$
\psi_t = \kappa_t \psi_t - \kappa_t \psi_t x_t + \mu_t
$$

Thus, we have that

$$\psi_t = \frac{\mu_t}{1 - \kappa_t + \kappa_t x_t}$$

Similarly, we can derive for foreign financial intermediary:

$$\psi_t^* = \frac{\mu_t^*}{1 - \kappa_t^* + \kappa_t^* x_t^*}$$

C Data Sources

In this appendix, I report the details of the data that are used in this paper, including detailed explanation on the collection and construction.

The nominal exchange rate data are from Datastream. I construct quarterly nominal exchange rate series between the U.S. and G10 countries: Australia, Canada, Euro Zone Area, Denmark, Japan, New Zealand, Norway, Sweden, Switzerland and the United Kingdom. The log U.S. dollar exchange rate is the equal-weighted average of the log exchange rates against the G10 countries. Sample period: 2000 - 2017 quarterly.

CPI data form IMF Consumer Price Index (CPI) 2000-2017 quarterly.

Treasury bond rate and G10 country government bond rate at one-year maturity. Source: Bloomberg and Datastream. Sample period: 2000 - 2017 quarterly.

LIBOR rate at one-year maturity. Source: Bloomberg and Datastream. Sample period: 2000 - 2017 quarterly.

Bank's ROA. Source: FRED. Sample period: 2000 - 2017 quarterly.

Treasury holdings: Treasury International Capital (TIC) System. Under statistics-2-B-A-2 (MFH Tables).

Equity holdings: Treasury International Capital (TIC) System. Download from Foreign Portfolio Holdings of U.S. Securities and U.S. Portfolio Holdings of Foreign Securities data time 2003-2017 annual

Banks' leverage ratio. Measurement: $\frac{\text{Total Risky Assets}}{\text{Total Assets - Total Liabilities}}$. Source: Financial Account Database of the U.S. reported by the Federal Reserve Board. Sample period: 2000 - 2017 quarterly.

GDP: OECD. Under National Accounts - Quarterly National Accounts - Historical GDP - expenditure approach.

Consumption. Source: Annually data from World Bank national accounts data, and OECD National Account data files. Sample period: 2000 - 2017 annually.

Value-at-risk and total assets of banks. Source: Bloomberg. Sample period: 2000 - 2017 quarterly.

Net foreign asset. IMF Balance of Payments and International Investment Position. It is computed by Financial Assets, U.S. Dollars minus Liabillities, U.S. Dollars.

Net investment income. IMF Balance of Payments and International Investment Position. It is computed as Current Account, Investment Income, Credit, US Dollars minus Current Account, Investment Income, Debit, US Dollars from Balance of Payments.