Intermediary Leverage and Currency Risk Premium*

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Abstract

This paper proposes an intermediary-based explanation of the risk premium of currency carry trade in a model with a cross-section of small open economies. In the model, bankers in each country lever up and hold interest-free cash as liquid assets against funding shocks. Countries set different nominal interest rates, while low interest rates encourage bankers to take high leverage. Consequently, bankers' wealth drops sharply with a negative shock. This reduces foreign asset demand and leads to a domestic appreciation, which in turn makes low-interest-rate currencies good hedges. The model implies covered interest rate parity deviations when safe assets differ in liquidity. The empirical evidence is consistent with the main model implications: (i) Low-interest-rate countries have high bank leverage and low currency returns; (ii) the carry trade return is procyclical with a positive exposure to the bank stock return; and (iii) comovement of the carry trade return and the stock return increases with the stock market volatility.

Key Words: Bank leverage, Carry trade, Currency risk premium, Exchange rate, Liquidity premium, Nominal interest rate

JEL Classification: E40, F31, G15, G21

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1 Introduction

Investors earn sizable excess returns on average by borrowing low-interest-rate currencies (such as Japanese yen) and investing in high-interest-rate currencies (such as Australian dollar). This investment strategy is famously known as carry trade. One widely-used approach to explain the phenomenon is based on risk (Lustig and Verdelhan, 2007; Lustig, Roussanov, and Verdelhan, 2011), which argues that low-interest-rate currencies are less risky than high-interest-rate ones. In other words, low-interest-rate currencies appreciate relative to high-interest-rate ones in bad times. However, there is no consensus yet on the sources of currency risks. In this paper, we propose a *liquidity-leverage* channel on how nominal interest rates affect currency risk premia through financial intermediaries. We build a dynamic model in which low-interest-rate currencies appreciate in bad times relative to high-interest-rate ones. As a result, investors require a positive risk premium to conduct carry trades.

Our model features a cross-section of small open endowment economies that differ in their nominal interest rates as exogenous policy choices. These economies are separate from each other and face a common foreign security whose foreign currency denominated return is exogenously given. In each economy, there are two types of agents (h and b) with heterogeneous preferences: the type-h agent has higher risk aversion and lower IES than the type-b agent [1]. Throughout the paper, the type-b agent is called a "banker" and the type-h is a "household." In equilibrium, the type-b agent borrows from the type-h by issuing a riskless deposit, and thus plays the role of a bank in the economy. While taking leverage, bankers face a liquidity shock (Drechsler, Savov, and Schnabl, 2018), which leads to the request of withdrawal from the bankers. Since the risky assets held by the bankers are illiquid and liquidating them incurs a large firesale loss, bankers voluntarily hold interest-free cash as liquid assets to be insulated from being affected by the funding shock. Consequently, the interest rate represents the opportunity cost of leverage, and bankers in low-interest-rate countries take high leverage.

When a negative endowment shock hits a low-interest-rate country, the wealth share of bankers sharply decreases in that country, because the bankers are highly levered. Since bankers have higher IES than households do, the wealth-weighted consumption-wealth ratio of that country increases, which induces a sharp decrease of the foreign asset demand. The domestic currency consequently appreciates, making it a good hedge against adverse endowment shocks. We call this channel the *liquidity-leverage* channel throughout this paper. On the contrary, if the same negative shock hits a high-interest-rate country with low bank leverage, the response of bankers' wealth share is weaker, thus the exchange rate movement is milder. Therefore, the high-interest-rate currencies are not as good hedges as the low-interest-rate ones, and investors require a positive premium for the carry trade.

Our model has rich implications for the factor structures of the asset returns. Lustig et al.

[1] Empirical evidence shows that investors that hold more risky assets have higher IES (Vissing-Jørgensen, 2002). Guvenen (2009) proposes a model with high-IES stock-holders, matching both asset prices and macro dynamics quantitatively.

(2011) empirically show that the cross-section of currency portfolio returns can be priced by the carry risk factor, defined as the spread between returns of investing in high- and low-interest-rate currencies. In our model, the carry risk factor measures the magnitude of the common endowment shock faced by all countries: When the shock is positive, the carry risk factor becomes large. Consequently, low-interest-rate currencies depreciate when the carry risk factor is large, consistent with the empirical finding.

Furthermore, our model delivers a factor structure of stock valuations (Colacito, Croce, Gavazzoni, and Ready, 2018) that stock prices of low-interest-rate countries load more on the global risk. In our model, when the same shock hits all the economies, stock valuations of low-interest-rate countries rise more because of high bank leverage.

We derive a new factor structure of the currency returns with the cross-sectional average of bankers' return to wealth in the model. When a common positive shock hits all the countries, bankers' wealth increases in every country while the magnitude declines with the interest rate and bank leverage. The heterogeneity in wealth redistribution across countries lead to low-interest-rate currencies' depreciation relative to high-interest-rate ones in good times. In other words, carry trade is procyclical; and the exposure of currency carry trade return to bankers' return to wealth increases with the interest rate. In our empirical analysis, we verify this implication by measuring the return to bankers' wealth with the banking sector stock return in each country.

Dynamically, the factor structure of the exchange rate and the average stock return is time-varying. The time variation is first noted by Lustig, Roussanov, and Verdelhan (2008), wherein that the currency carry trade beta with stock return is particularly high during a crisis. Since our model does not have a clear-cut definition of a crisis, we examine the correlation between currency carry trade beta and the stock market volatility. In the model, beta increases with the stock market volatility. The reason is simple: exchange rates co-move with stock returns when the amplification effect brought by leverage is strong. This is exactly when the endogenous volatility of stock return is high. We document this feature in the data in the empirical analysis. The implication of the dynamic property of beta distinguishes our model from most of the existing literature.

After exploring the cross-sectional implications on interest rates, bank leverage, exchange rates, and stock prices, we analyze the time-series relationship between interest rates and currency risk premia by introducing stochastic interest rates into the model. If a country experiences an unexpected rise in the interest rate, bankers in that country take less leverage and the required risk premium to invest abroad decreases. This result is in line with the empirical finding of Mueller, Tahbaz-Salehi, and Vedolin (2017), wherein that the subsequent return of investing abroad is lower (higher) after the Federal Open Market Committee raises (cuts) the interest rate. Moreover, our model implies that the regression coefficient of foreign excess return on the interest rate differential between foreign and domestic currency is positive, consistent with the long-standing literature on the "forward premium puzzle".

Our model delivers two additional results that are consistent with the recent empirical literature.

Du, Tepper, and Verdelhan (2018b) document the large and persistent deviations from covered interest rate parity (CIP) after the financial crisis, while Jiang, Krishnamurthy, and Lustig (2018) and Du, Im, and Schreger (2018a) show that dollar safe assets have privilege over foreign ones. In our model, the return to CIP arbitrage with a long dollar position is negative if the dollar safe assets are more liquid. Jiang et al. (2018) take a further step and find that the "liquidity premium" of the dollar has a positive correlation with the risk premium of investing in dollar assets. In a slightly extended version of our model, when domestic and dollar assets are imperfectly substitutable liquid assets, a rise in dollar liquidity premium reduces the total cost of holding liquidity for foreign investors. This is effectively similar to a drop in the nominal interest rate, so that the risk premium to invest in the dollar increases.

Despite the parsimony of the liquidity friction that only cash is held as the liquid asset, our model captures a wide range of regulation and market discipline practices concerning liquidity. The regulations include reserve requirement ratio for depository institutions, and more recent liquidity coverage ratio required by the Basel III framework. Apart from regulations, financial institutions also voluntarily hold liquid assets. In our model, we have the interest-free cash as the single type of liquid assets available. However, the model can be easily extended to incorporate other near-money safe assets that provide liquidity, such as government treasuries. The different liquidity properties of these assets lead to different liquidity premia. Nagel (2016) presents detailed empirical evidence to show that liquidity premia of near-money assets are tightly linked to the nominal interest rate.

Our *liquidity-leverage* mechanism is different from other models of cross-sectional currency risk premia. Existing studies (For example, Hassan, 2013; Richmond, 2018; Ready, Roussanov, and Ward, 2017) propose some source of fundamental heterogeneity (e.g, country size, trade network centrality, and composition of trade, respectively) across countries that simultaneously drive interest rates and currency risk premia. While most advanced economies use the nominal interest rate as their monetary policy tools, the literature is largely silent on how nominal interest rates are translated into exchange rate properties. In our paper, the nominal interest rates are taken as exogenous policy choices and real exchange rate dynamics are determined by the leverage of bankers, which in turn, depends on nominal interest rates. Our *liquidity-leverage* channel thus complements the existing literature.

The empirical analysis of this paper is centered around three main model implications: (i) low-interest-rate countries have high bank leverage and low currency returns; (ii) the carry trade return is procyclical with a positive exposure to bank stock return; (iii) comovement of the carry trade return and the stock return increases with the stock market volatility.

As the first-pass validation of implication (i), Figure 1 plots the cross-sectional relation of bank capital ratio (the inverse of bank leverage, in percent) with average forward discounts (interest rate differentials) and currency returns vis-a-vis the dollar for the ten most liquid currencies. A positive slope stands out in both graphs: Countries with lower bank capital ratio (higher leverage) tend to have lower interest rates and currency returns. The typical carry trade funding country (Japan) has substantially lower capital ratio than the typical investment country (Australia). In the empirical section, we show the same relationship for 22 advanced economies through panel regressions. The relationship is robust after controlling for each country's inflation and GDP. Following standard asset pricing practice, we sort currencies into portfolios based on bank leverage, and find that currency returns monotonically increase from high leverage portfolios to low leverage portfolios. The spread between the lowest and highest leverage portfolios, the "Lev-factor," is 2.0 percent per annum. Heterogeneous exposures to the "Lev-factor" accounts for the different expected returns of currency portfolios and the "Lev-factor" has a significantly positive risk price, which is consistent with our model implication.

To validate implication (ii), we construct a measure of the common endowment shock by averaging the banking sector stock returns across countries in the sample. The use of banking sector return is to highlight the role of banks in driving exchange rates, while we show the same results hold if we replace bank stock returns with country-level stock return indices in the appendix. Exposures of currency returns to the bank stock return are in line with countries' average interest rate—low-interest-rate currencies have lower (more negative) exposures than high-interest-rate ones. In other words, carry trade is highly procyclical.

Lastly, we examine implication (iii), the time variation of carry trade return's comovement (beta) with the stock market return. We construct the stock return risk factor by averaging the MSCI country indices and calculate the carry trade betas based on five-year rolling windows. Carry trade betas increase in the average stock return volatility, computed as the realized volatility of monthly average stock returns in the same five-year window.

This paper makes three contributions to the literature. First, we provide a new explanation of the currency risk premium featuring the *liquidity-leverage* channel, with nominal interest rates as exogenous monetary policy choices. Our model can accommodate many empirical findings in the literature, including the factor structure of currency and stock returns, CIP deviation, and the positive relationship between the liquidity premium and the risk premium of the dollar. Second, our model can simultaneously explain the time-series and cross-sectional relationship between interest rates and risk premia. Third, our empirical evidence is in line with the main model implications, especially the novel relation between interest rate, bank leverage, and currency returns in the cross-section.

Related Literature

Our paper is closest to three papers in the literature. Backus, Gavazzoni, Telmer, and Zin (2013) link currency risk premium to monetary policy heterogeneity across countries, but the real side of the economy is not affected by monetary policy. In our model, monetary policy affects currency risk premium in real terms. Maggiori (2017) shows that currencies of countries with a more developed financial system (such as US) appreciate in bad times, while Malamud and Schrimpf (2018) derive exchange rate dynamics from a model with monopolistic intermediaries. Neither of these two papers links currency risk premia to different countries' interest rate levels. In both of the two papers, only intermediaries have access to the foreign asset while we relax this assumption to allow both households and bankers to freely trade the foreign asset. Moreover, our paper provides empirical evidence in support of the key mechanism of our model, while both Maggiori (2017) and Malamud and Schrimpf (2018) are theoretical studies.

Lustig and Verdelhan (2007) and Lustig et al. (2011) document the systemic variation of currency returns for cross-sectional interest rate sorted portfolios and construct pricing factors. However, these papers are silent on how economic fundamentals determine exchange rates. Economic explanations to sources of currency risk premium highlight the fundamental heterogeneity across countries, including monetary policy (Backus et al., 2013), country size (Hassan, 2013), trade network centrality (Richmond, 2018), composition of international trade (Ready et al., 2017), long run risk exposure (Colacito et al., 2018), fiscal cyclicality (Jiang, 2018), and dollar external debt (Wiriadinata, 2018). Our paper takes a different perspective by taking nominal interest rates as exogenous policy choices and proposes the *liquidity-leverage* channel that links nominal interest rate and currency risk premium.

On the other hand, the literature on time-series violation of uncovered interest rate parity has been vast since Fama (1984). The robust positive comovement between currency returns and interest rate diffentials poses challenges to exchange rate modeling. Early studies with the asset pricing approach include Bekaert (1996), Bansal (1997), Backus, Foresi, and Telmer (2001), and Brennan and Xia (2006). Structural macro-finance models explain the forward premium puzzle under a frictionless financial market(Verdelhan, 2010; Stathopoulos, 2016; Bansal and Shaliastovich, 2013; Colacito and Croce, 2013; and Farhi and Gabaix, 2015). Alternatively, some studies introduce financial market imperfections into standard models, such as Alvarez, Atkeson, and Kehoe (2009); Favilukis and Garlappi (2017); Gabaix and Maggiori (2015); and Fang and Liu (2018), and so on. Valchev (2017) explains deviation from uncovered interest rate parity by introducing a convenience yield difference between the domestic and foreign bonds. In our paper, there is no liquidity difference between the domestic deposit and the foreign bond. Instead, nominal interest rate (liquidity premium) affects the cyclicality of exchange rates through changing the leverage choices of the bankers in the economy.

Recent literature highlights the role of intermediaries in exchange rate determination. For instance, empirical asset pricing literature shows the pricing power of intermediary variables on currency returns (Adrian, Etula, and Shin, 2015; Adrian, Etula, and Muir, 2014; He, Kelly, and Manela, 2017; Haddad and Muir, 2017). Sandulescu, Trojani, and Vedolin (2017) derive model-free international SDFs and show they are highly correlated with intermediary variables. Itskhoki and Mukhin (2017) demonstrate that the financial asset demand wedge is crucial in explaining exchange rate dynamics. Our model highlights the liquidity frictions faced by intermediaries, while the effect of the friction depends on nominal interest rates. Moreover, our model explains the relationship between interest rates and currency risk premia in both cross-sectional and time-series dimensions.

Our paper is related to the literature on the risk-taking channel of monetary policy. The model framework and the *liquidity-leverage* channel is similar to Drechsler et al. (2018), while we extend the model to the open economy. Bruno and Shin (2015) and Dell'Ariccia, Laeven, and Suarez (2017) show that banks play important roles in the risk-taking effect of monetary policy. Rey (2016) and Miranda-Agrippino and Rey (2018) demonstrate that intermediary credit and leverage are important in monetary transmission across the border. Our *liquidity-leverage* channel thus bridges the literatures on the risk-taking effect of monetary policy and currency risk premium.

Methodologically, our model falls into the category of international finance models with endogenous asset prices and portfolio decisions. Coeurdacier (2009), Devereux and Sutherland (2011), and Stepanchuk and Tsyrennikov (2015) are models solved in discrete time, while Baxter, Jermann, and King (1998), Jermann (2002), Pavlova and Rigobon (2007), and Pavlova and Rigobon (2012) solve continuous-time versions of such models[2]. Our model is in continuous time, but the solution is obtained by numerically solving the fixed-point of an incomplete market economy, which is different from Pavlova and Rigobon (2012).

The rest of the paper is organized as follows. Section 2 lays out the structure of the model and derives equilibrium conditions. Section 3 shows the solutions and simulation results of the model. Section 4 provides empirical evidence on the main model implications. Section 5 concludes the paper.

2 The Model

The world consists of a cross-section of $N+1$ small open economies. Each economy is populated with two types of agents. Both agents consume two goods: a country specific nontraded good and a common traded good. Country 1 is labeled as the provider of a global riskless asset denominated in its local nontraded good. Agents in all economies have access to the global riskless asset. We abstract away the optimization behavior of Country 1's agents, and exogenously assume the relative price of country 1's nontraded good in the traded good. The remaining N countries are symmetric, except that they have different nominal interest rates. In the next section, we describe the economic environment of a typical small open economy.

2.1 Environment

Consider a representative small open endowment economy. There are two types of goods in the economy: nontraded goods (X) and traded goods (Y). Traded goods can be exported to or imported from other countries. Time is continuous and infinite. Uncertainty is characterized by a standard filtered probability space $(\Omega, \mathcal{F}, \mathbb{P}, \{\mathbf{F}_t\})$, to which all stochastic processes are adapted. The structure of the model is close to Drechsler et al. (2018) except for its open economy features.

[2]See Coeurdacier and Rey (2013) for a complete survey of the literature.

2.1.1 Endowment

The economy is endowed with a tree that pays dividends in both nontraded and traded goods. The dividend process of the nontraded good (X) follows a geometric Brownian motion:

$$\frac{dX}{X} = \mu_x dt + \sigma_x dB_x \tag{1}$$

μ_x, σ_x are positive constants. The traded good endowment (Y) is given by:

$$Y = \bar{\tau} X \tag{2}$$

with $\bar{\tau}$ being a constant.

2.1.2 Agents

The economy is populated with two types of agents (h and b). Both agents have recursive utility, as in Duffie and Epstein (1992). We denote ψ_j and γ_j as agent j's intertemporal elasticity of substitution (IES) and risk aversion. All parameters without subscript j are common to both agents. The lifetime utility of agent j at time t, V_t^j is given by:

$$V_t^j = \int_t^\infty f^j(C_\tau^j, V_\tau^j) d\tau \tag{3}$$

where:

$$f^j(C^j, V^j) = \frac{1-\gamma_j}{1-\frac{1}{\psi_j}} V^j \left\{ \left[\frac{C^j}{[(1-\gamma_j)V^j]^{\frac{1}{1-\gamma_j}}} \right]^{1-\frac{1}{\psi_j}} - \rho \right\} \tag{4}$$

ρ is the time discount factor. C^j is agent j's consumption basket, a constant elasticity of substitution (CES) aggregation of nontraded and traded good consumption:

$$C^j = \left[\alpha (C_x^j)^{\frac{\theta-1}{\theta}} + (1-\alpha)(C_y^j)^{\frac{\theta-1}{\theta}} \right]^{\frac{\theta}{\theta-1}} \tag{5}$$

α measures the relative preference of the nontraded good over the traded good. θ is the elasticity of substitution between the two goods.

The two agents differ in both risk aversion and IES. Type-b agents have lower risk aversion and larger IES than type-h agents: $\gamma_h > \gamma_b$ and $\psi_h < \psi_b$. The assumption implies that it is more desirable for type-h agents to have a smooth consumption profile across states of the world as well as across time. This assumption is consistent with the empirical evidence that investors with more holdings of risky asset have higher IES (Vissing-Jørgensen, 2002). Moreover, it is consistent with the assumption made by Guvenen (2009)—that stock-holders have higher IES [3]. In equilibrium,

[3] In Guvenen (2009), the two types of agents are homogeneous in risk aversion but one type is excluded from holding stocks. In our model, heterogeneity in risk aversion endogenously generates the heterogeneous holdings of the risky asset

type-b agents borrow from type-h agents in the form of riskless deposits (denominated in local nontraded good) and essentially play the role of banks in the economy. In the rest of the paper, I will call type-h agents as "Households," and type-b agents as "Bankers."[4]

We assume that a κ fraction of agents exit the market with the same measure of agents newly born from t to $t + dt$. The wealth of exiting agents is transferred to the newly borns on an equal per capita basis. This assumption is standard in the two-agent dynamic models since it prevents one type of agent from dominating the other.

2.1.3 Assets

Each agent has four assets to choose from: a riskless asset denominated in the local nontraded good (deposit), a claim to the local tree (local stock), a foreign security that is risk free in Country 1's nontraded good (foreign bond), and the country specific cash that pays zero nominal interest rate (cash). The return characteristics of these assets are as follows.

Deposit is risk free in terms of the local nontraded good, with an instantaneous real risk-free rate r_t that is endogenously determined by the intertemporal choices of the agents.

The return process of the local stock is:

$$dR_s = \frac{X + QY}{P}dt + \frac{dP}{P} \equiv \mu_s dt + \sigma_s' d\mathbf{B} \tag{6}$$

where P is the price of the local stock denominated in the nontraded good, while $\frac{1}{Q}$ is the relative price of the local nontraded good in the traded good. μ_s and σ_s are the endogenous drift and diffusion of the local stock return process. We group all the Browian shocks into the vector $\mathbf{B}$, to be specified toward the end of this section.

The instantaneous return to foreign bond in Country 1's nontraded good is r^*. The price of Country 1's nontraded good $\frac{1}{Q^*}$ follows the following exogenous process[5]:

$$\frac{dQ^*}{Q^*} = \sigma_q^* dB_q^* \equiv \sigma^* d\mathbf{B} \tag{7}$$

With a postulated endogenous Q process:

$$\frac{dQ}{Q} = \mu_q dt + \sigma_q d\mathbf{B} \tag{8}$$

We can express the foreign bond return process in the local nontraded good as:

$$dR_f^* = (r^* + \mu_q + \sigma_q' \sigma^*)dt + (\sigma_q + \sigma^*)d\mathbf{B} \equiv \mu_f dt + \sigma_f' d\mathbf{B} \tag{9}$$

across the two types.

[4]In our model, bankers represent broadly defined commercial banks, investment banks, hedge funds, broker dealers, and other leveraged financial institutions.

[5]Any drift in the Q^* process can be absorbed in r^*.

μ_f, σ_f are the endogenous drift and diffusion of the foreign bond return in the local nontraded good.

Agents can hold cash that does not pay interest. We introduce a friction to create an incentive for agents to hold cash despite its zero interest. When an agent borrows to buy illiquid assets, she holds cash as the liquid asset to be insulated from the funding shock. The details are laid out in section 2.2.

2.1.4 Nominal Interest Rates as Policy Choices

We consider two versions of the model. The baseline version features constant nominal interest rates, while in the second version, we introduce nominal interest rate shocks. Central banks use nominal interest rates as policy tools. When stochastic, nominal interest rates follow Orstein-Uhlenbeck processes:

$$di = \zeta(i_0 - i)dt + \sigma_i dB_i \tag{10}$$

Different countries have different means of nominal interest rate, i_0. $\zeta > 0$ governs the persistence of nominal interest rates, and σ_i controls their volatility.

To summarize, there are two Brownian shocks in this economy if nominal interest rates are fixed: B_x and B_q^*. Thus, the vector $\mathbf{B}$ is defined as a column vector:

$$\mathbf{B} = [B_x, B_q^*]' \tag{11}$$

If nominal interests are stochastic, we have an additional interest rate shock: B_i.

Our model features incomplete financial market in two aspects. First, agents in different countries are segmented: they do not have access to the trees in other countries. Second, cash holding impedes risk sharing across agents in one country.

Without loss of generality, throughout the paper, we define "real exchange rate" as the reciprocal of the country-specific nontraded good price in the traded good (Q).

2.2 The Liquidity Friction

This section analyzes in detail the main friction in the economy: the liquidity friction. In every instant from t to $t + dt$, a Poisson funding shock hits the economy at rate η. Once hit, all lenders (both domestic and foreign) will request for a withdrawal of $\frac{\lambda}{1+\lambda}$ fraction of their assets.

The borrowers can hold four assets, while each asset differs in its liquidity. "Liquidity" is defined as how much proportion of an asset that can be liquidated to meet withdrawal needs costlessly when the funding shock hits the economy. The liquidity of each asset is as follows:

The $\frac{\lambda}{1+\lambda}$ fraction of deposit or foreign bond can be liquidated without additional costs. If an agent wants to sell more, she has to pay a firesale loss of ϕ for each unit. Local stocks can be sold only at a fire sale price with loss ϕ per unit, while all cash can be used to meet the withdrawal needs costlessly.

To summarize, the assets are ranked according to liquidity as:

$$\text{Cash} > \text{Deposit} = \text{Foreign bond} > \text{Local stock}$$

We define L_D^j as the liquidity need of agent j when the funding shock hits, and L_H^j as the available assets owned by agent j that can be liquidated costlessly.

We denote w_h^j, w_f^j, w_c^j as agent j's portfolio share in local stock, foreign bond, and cash, so that $1 - w_h^j - w_f^j - w_c^j$ is her portfolio share in the deposit. The liquidity need (in portfolio share) when the funding shock hits is:

$$L_D^j = \frac{\lambda}{1+\lambda}\left[\max\{w_h^j + w_c^j + w_f^j - 1, 0\} + \max\{-w_f^j, 0\}\right] \tag{12}$$

The first term is the liquidity need from domestic lenders, while the second term is the liquidity need from foreign lenders. Meanwhile, the available share of liquid assets agent j holds is:

$$L_H^j = \frac{\lambda}{1+\lambda}\left[\max\{1 - w_h^j - w_c^j - w_f^j, 0\} + \max\{w_f^j, 0\}\right] + w_c^j \tag{13}$$

The term in the bracket is the amount of deposit and foreign bond that can be used to repay without cost. All cash w_c^j can be used to meet the liquidity need.

If an agent holds more liquid assets than needed ($L_H^j > L_D^j$), she can fully protect herself from the funding shock. Otherwise, she has to fire-sell $L_D^j - L_H^j$ of illiquid assets and incur a loss.

The function of cash in the economy is to provide liquidity to insulate borrowers from the funding shock. If agent j holds one unit of cash, an additional liquidity of $\frac{1}{1+\lambda}$ is provided. In fact, our model can incorporate a wide range of safe assets that differ in their liquidity properties. The yields of these safe assets are determined by how much liquidity they can provide. Consider another safe asset (e.g., treasury bill) that wherein $\frac{\tilde{\lambda}}{1+\lambda}$ fraction can be liquidated costlessly. The nominal yield to treasury bill x satisfies:

$$\frac{i}{1 - \frac{\lambda}{1+\lambda}} = \frac{i - x}{\frac{\tilde{\lambda}-\lambda}{1+\lambda}} \tag{14}$$

The left-hand side is the price of liquidity for cash, while the right-hand side is the price of liquidity for treasury bills. Suppose borrowers are indifferent in holding the two assets, then the price of liquidity should be identical across the two assets. Therefore, we can solve for the following:

$$x = (1 - \tilde{\lambda} + \lambda)i \tag{15}$$

If $\tilde{\lambda} > \lambda$, the treasury bills are more liquid than the deposits. Thus, the treasury yield is smaller than the nominal interest rate.

We abstract from modeling the different liquidity properties between the foreign bond and the deposit, so that the excess return to the foreign bond only consists of a risk premium component.

This assumption also simplifies analysis by ensuring all policy functions to be smooth.

2.3 Agents' Optimization Problem

In this section, we characterize the optimization problem for agent j ($j = h, b$). The nominal price of nontraded good (numeraire) is assumed to be locally deterministic. Agent j solves the following optimization problem:

$$V_0^j = \max_{c_x^j, c_y^j, w_h^j, w_f^j, w_c^j} E \int_0^\infty f^j(C_t^j, V_t^j) dt \tag{16}$$

$$s.t. : \frac{dW^j}{W^j} = \left[r - c_x^j - Qc_y^j + w_h^j(\mu_s - r) + w_f^j(\mu_f - r) + w_c^j(-i) \right] dt + (w_h^j \sigma_s + w_f^j \sigma_f)' d\mathbf{B}$$
$$+ \Pi^j dt - \frac{\phi}{1-\phi} \max(L_D^j - L_H^j, 0) dN \tag{17}$$

$$c^j = \left[\alpha (c_x^j)^{\frac{\theta-1}{\theta}} + (1-\alpha)(c_y^j)^{\frac{\theta-1}{\theta}} \right]^{\frac{\theta}{\theta-1}} \tag{18}$$

Agent j chooses optimal consumption of both the nontraded good c_x^j and the traded good c_y^j, as well as portfolio shares w_h^j, w_f^j, and w_c^j, taking return processes as given. c_x^j, c_y^j are consumption C_x^j, C_y^j scaled by wealth W^j. N is a non-decreasing count process with arrival rate η, which represents the funding shock. Π^j is the lump-sum wealth transfer to agent j.

L_D^j is the liquidity demand for withdrawal when the funding shock hits, and L_H^j is agent j's available liquid assets, defined in equations (12) and (13). If the funding shock hits, agent j has to fire sell $L_D^j - L_H^j$ of illiquid assets and incurs a loss of $\frac{\phi}{1-\phi}$ per unit of fire sale.

The following proposition characterizes the HJB equation for agent j:

Proposition 1 *The value function of agent j can be written as:*

$$V^j(W^j; \Omega) = \frac{(W^j)^{1-\gamma_j}}{1-\gamma_j} \left[G^j(\Omega) \right]^{\frac{1-\gamma_j}{1-\psi_j}} \tag{19}$$

$G^j(\Omega)$ satisfies the following Partial Differential Equations (PDE):

$$0 = \max_{c_x^j, c_y^j, w_h^j, w_c^j, w_f^j} \left\{ \frac{1}{1-\frac{1}{\psi_j}} \left(\frac{c^j}{G^j} \right)^{1-\frac{1}{\psi_j}} G^j - (\rho + \kappa) \right\} + \mu_w^j - \frac{1}{2}\gamma_j (\sigma_w^j)' \sigma_w^j + \frac{1}{1-\psi_j} \nabla G^j \mu_\Omega$$
$$+ \frac{1}{2} \frac{1}{1-\gamma_j} tr(\Sigma_\Omega' \Sigma_\Omega \mathcal{H} G^j) + \frac{1}{1-\psi_j} \frac{\psi_j - \gamma_j}{1-\psi_j} \nabla G^j \Sigma_\Omega' \Sigma_\Omega (\nabla G^j)' + \frac{1-\gamma_j}{1-\psi_j} \nabla G^j \Sigma_\Omega' \sigma_w^j + \eta (V_+^j - V^j) \tag{20}$$

where c^j is defined in equation (18), and:

$$\mu_w^j = r - c_x^j - Qc_y^j + w_h^j(\mu_s - r) + w_f^j(\mu_f - r) - w_c^j i + \Pi^j \tag{21}$$

$$\sigma_w^j = w_h^j \sigma_s + w_f^j \sigma_f \tag{22}$$

Ω represents the vector of aggregate state variables. Π^j is the lump-sum wealth transfer. ∇G^j is the gradient (row) vector of function G^j, while $\mathcal{H}G^j$ is the Hessian matrix of G^j. μ_Ω is the column vector for state variable drift, while Σ_Ω is the matrix for state variables' diffusions, with each column representing one state variable's exposures to various Brownian shocks. $V_+^j = V^j(W_+^j, \Omega)$, and W_+^j is the wealth of agent j following a funding shock.

Note that agent j has κ probability to exit the market. It is equivalent to changing agent j's time discount rate from ρ to $\rho + \kappa$. A complete, term-by-term exhibition of the HJB equation can be found in Appendix B, equation (83).

We assume that the nominal price of nontraded good is locally deterministic. This assumption serves as an equilibrium selection criterion and abstracts away the inflation risk[6].

We proceed in two steps: First, we derive agents' optimal cash holding; second, we solve for the optimal consumption and portfolio choice decisions.

2.3.1 Optimal Cash Holding

The incentive to hold cash as liquid assets depends on the tradeoff between its benefit of avoiding a fire sale loss and nominal interest rate, the opportunity cost of holding cash. We impose the following restriction on parameters η, λ, ϕ, i.

Assumption 1 *Parameters of η, ϕ, λ satisfy[7]:*

$$\eta \frac{\phi}{1-\phi} \frac{1}{1+\lambda} > i \tag{23}$$

The left-hand side is the expected fire sale loss if the borrower marginally reduces one unit of cash holding and incurs a firesale loss. The right-hand side—nominal interest rate—measures the opportunity cost of holding cash. Under Assumption 1, the benefit of holding cash overweighs the cost. Therefore, the fire sale will never happen in equilibrium, as shown in Proposition 2:

Proposition 2 *Agent j chooses to insulate herself from the funding shock:*

$$\max(L_D^j - L_H^j, 0) = 0 \tag{24}$$

A formal proof is provided in Appendix A.1. The intuition for full insurance is that the benefit of avoiding fire sale overweighs the cost of holding cash.

The next proposition derives the optimal portfolio share on cash holding.

[6] Hollifield and Yaron (2003) show currency risk premium is mainly compensation for real risks instead of inflation risks.

[7] This is a sufficient assumption (not necessary) to ensure agents to hold enough cash to protect themselves from being exposed to the funding shock.

Proposition 3 *Agent j's optimal cash holding depends on her local stock holding*

$$w_c^j = \max\{\lambda(w_h^j - 1), 0\} \tag{25}$$

The proof of the proposition is shown in Appendix A.2. The intuition here is that, if agent j's portfolio constitutes liquidity transformation, she is exposed to the funding shock and needs to hold cash for liquidity service. The only liquidity transformation occurs when the agent borrows (either from home or abroad) to buy the local stock. Therefore, only the portfolio share on the local stock matters for cash holding. If $w_h^j < 1$, there is no liquidity transformation, so that no cash holding is needed. If $w_h^j > 1$, agent j transforms $w_h^j - 1$ units of liquid liabilities to the illiquid local stock, and voluntarily holds cash proportionally. We assume that all the forgone interests are rebated back to the bankers.

Meanwhile, borrowing from home and investing in the foreign bond does not require additional cash holding, since the deposit and the foreign bond have the same liquidity. We make this simplifying assumption so that the excess return of foreign bond investment purely comes from the risk premium component.

2.3.2 Optimal Consumption and Portfolio Choice

The following two corollaries derive agents' optimal consumption and portfolio decisions.

Corollary 1 *Agent j's optimality conditions for (20) is given by:*

$$\alpha(\frac{c^j}{G^j})^{-\frac{1}{\psi_j}}(\frac{c^j}{c_x^j})^{\frac{1}{\theta}} = 1 \tag{26}$$

$$(1-\alpha)(\frac{c^j}{G^j})^{-\frac{1}{\psi_j}}(\frac{c^j}{c_y^j})^{\frac{1}{\theta}} = Q \tag{27}$$

If $w_h^j \geq 1$*:*

$$\begin{bmatrix} w_h^j \\ w_f^j \end{bmatrix} = \frac{1}{\gamma_j}(\Sigma'\Sigma)^{-1}\begin{bmatrix} \mu_s - r - \lambda i \\ \mu_f - r \end{bmatrix} + \frac{1-\gamma_j}{1-\psi_j}\frac{1}{\gamma_j}(\Sigma'\Sigma)^{-1}\Sigma_\Omega'\Sigma(\nabla G^j)' \tag{28}$$

$$w_c^j = \lambda(w_h^j - 1) \tag{29}$$

If $w_h^j < 1$*:*

$$\begin{bmatrix} w_h^j \\ w_f^j \end{bmatrix} = \frac{1}{\gamma_j}(\Sigma'\Sigma)^{-1}\begin{bmatrix} \mu_s - r \\ \mu_f - r \end{bmatrix} + \frac{1-\gamma_j}{1-\psi_j}\frac{1}{\gamma_j}(\Sigma'\Sigma)^{-1}\Sigma_\Omega'\Sigma(\nabla G^j)' \tag{30}$$

$$w_c^j = 0 \tag{31}$$

where: $\Sigma = \begin{bmatrix} \sigma_s & \sigma_f \end{bmatrix}$*,* ∇G^j *is the (row) vector of the gradient of* G^j*, and* Σ_Ω *is the matrix for state variables' diffusions, with each column representing one state variable's exposure to various Brownina shocks.* $\Sigma_\Omega'\Sigma$ *is the covariance matrix between asset returns and state variables.*

This corollary is a standard result, except for the risk premium term is augmented with $-\lambda i$ if $w_h^j > 1$. We can see how the nominal interest rate affects portfolio decisions from equation (28). Throughout the model section, I define w_h^j as leverage choice if it exceeds 1[8].

The households are more risk averse and insured by the bankers. As a result, $w_h^b > 1, w_h^h < 1$. Bankers borrow to buy the local stock[9]. As we analyze in section 2.2, bankers conduct liquidity transformation in their portfolios and hold cash for liquidity purposes. The nominal interest rate represents the cost of leverage taking. When the nominal interest rate is lower, bankers will demand more of the local stock.

Corollary 2 shows the Euler equation for asset i and agent j:

Corollary 2 *The risk premium required by agent j for any asset return process dR_i is given by:*

$$RP_i^j = -\frac{d}{dt}cov\left(\frac{1-\gamma_j}{1-\psi_j}\frac{d(\tilde{P}c^j)}{\tilde{P}c^j} - \gamma_j\frac{dW^j}{W^j} - (1-\gamma_j)\frac{d\tilde{P}}{\tilde{P}}, dR_i\right) \tag{32}$$

where W^j is the wealth of agent j denominated in the nontraded good. $\tilde{P}$ is the price of the consumption basket, with:

$$\tilde{P}^{1-\theta} = \alpha^\theta + (1-\alpha)^\theta Q^{1-\theta} \tag{33}$$

$\tilde{P}c^j \equiv \frac{\tilde{P}C^j}{W^j}$, represents the consumption wealth ratio of agent j.

The proof is provided in Appendix A.3.

Corollary 2 is a standard result. The state price densities of agents with recursive preferences not only rely on instantaneous consumption growth, but also on the return to their wealth portfolios. Having multiple goods complicates the problem slightly by introducing $\tilde{P}$, the price of consumption basket into the state price density.

Note that for the local stock, $\mu_s - r = RP_h^h$ for households, but for bankers, the excess return of domestic stocks have two components: liquidity premium λi and risk premium $RP_h^b = \mu_s - r - \lambda i$. The risk premium component satisfies equation (32) for bankers. The excess return to the foreign bond satisfies equation (32) for both agents as it does not include a liquidity premium component. Particularly, for $j = h, b$:

$$RP_f^j = \mu_q + r^* - r + \sigma_q'\sigma^* = -cov\left(\frac{1-\gamma_j}{1-\psi_j}\frac{d(\tilde{P}c^j)}{\tilde{P}c^j} - \gamma_j\frac{dW^j}{W^j} - (1-\gamma_j)\frac{d\tilde{P}}{\tilde{P}}, \frac{dQ}{Q}\right) \tag{34}$$

[8] A more precise definition of leverage is $w_h^j + w_c^j + w_f^j\mathbb{I}(w_f^j > 0)$, where $\mathbb{I}$ is an indicator function. For the ease of illustration, we ignore the third term. We will choose the proper exogenous foreign asset return process so that both investors' portfolio share on foreign asset is small relative to the portfolio share on the local stock. This is consistent with the observation that a majority of the wealth in a country is in its local assets, or the "home bias" literature (Lewis, 1999). The second term w_c^j is proportional to $w_h^j - 1$ if it is positive.

[9] In the numerical section, we solve the model with the conjecture that bankers takw leverage with $w_h^b > 1$, and verify our conjecture after we obtain the solutions.

2.4 Market Clearing

The nontraded good market and the local stock market should clear:

$$C_x^h + C_x^b = X \tag{35}$$

$$P = W^h w_h^h + W^b w_h^b \tag{36}$$

Moreover, we define the total net foreign asset of the country NFA as:

$$NFA = W^h w_f^h + W^b w_f^b \tag{37}$$

The total wealth of the economy equals the value of the local stock plus value that of the net foreign asset:

$$W = W^h + W^b = P + NFA \tag{38}$$

By Walras' law, the market clearing condition for the deposit is automatically satisfied.

2.5 State Variable Dynamics

There are two endogenous state variables: the wealth share of households (ω), and scaled net foreign asset position of the economy (χ). We define χ in traded goods, so that the two state variables are expressed as:

$$\omega = \frac{W^h}{W^h + W^b}, \chi = \frac{\frac{NFA}{Q}}{X} \tag{39}$$

The dynamics of ω can easily obtained by using Ito's lemma:

$$d\omega = \omega(1-\omega)\left[c_x^h - c_x^b + Q(c_y^h - c_y^b) + (w_h^h - w_h^b)(\mu_s - r) + w_b^c i + (w_f^h - w_f^b)(\mu_f - r) + \Pi^h - \Pi^b\right] dt$$

$$+ \kappa(\bar{\omega} - \omega)dt + \omega(1-\omega)\left[(w_h^h - w_b^h)\sigma_s + (w_f^h - w_f^b)\sigma_f\right]' d\mathbf{B} \tag{40}$$

We can write out the dynamics of $\frac{NFA}{Q}$ from the balance of payment equation. That is:

$$d\left(\frac{NFA}{Q}\right) = (Y - C_y^h - C_y^b)dt + \frac{NFA}{Q} r^* dt + \frac{NFA}{Q}(\sigma^*)' d\mathbf{B} - \Pi^{NFA} dt \tag{41}$$

Equation (41) describes the three components of net foreign asset change: current account adjustment, valuation change, and the lump-sum transfer $\Pi^{NFA} = \eta \frac{NFA}{Q}$. The lump-sum transfer is from (to) the outside world to keep the scaled net foreign asset stationary, following Schmitt-Grohé and Uribe (2003). Then we can derive dynamics of χ easily using Ito's lemma:

$$d\chi = \left(\tau - \frac{C_y^h + C_y^b}{X} + \chi r^*\right) dt + \chi(\sigma^*)' d\mathbf{B} - \eta\chi dt \tag{42}$$

When we introduce stochastic interest rates, there is another state variable, the nominal interest rate, which follows equation (10).

3 Numerical Solution and Model Analysis

In this section, we solve the model numerically. After discussing the parameters in section 3.1, we study a cross-section of six economies with different fixed nominal interest rates from 0 to 5 percent in section 3.2 and section 3.3. In section 3.4, we introduce stochastic interest rates and examine the time-series relation between nominal interest rate and currency risk premium. Lastly, in section 3.5 we discuss two additional results of our model that are consistent with the recent empirical literature on exchange rates and currency returns, including the deviation of covered interest rate parity (CIP, Du et al., 2018b) and the positive relationship between the liquidity premium of dollar assets and the risk premium of investing in dollar (Jiang et al., 2018).

We solve the model using Chebyshev polynomial approximation with the collocation method. Tensor products are used to deal with multiple state variables. A detailed description of the solution procedure is provided in Appendix B.

3.1 Parameter Values

Table 1 presents the parameters for numerical solutions. All parameters are at the annual frequency.

The parameters are grouped into five sets. Panel A contains parameters of preferences. One key ingredient of this model is the preference heterogeneity between households and bankers. Households have higher risk aversion and lower IES than bankers. Heterogeneity in risk aversion determines the risk allocation and leverage, while heterogeneity in IES drives changes in intertemoral choice and exchange rate dynamics when wealth is redistributed between the two agents. We require a substantial heterogeneity in both parameters, so that we choose $\gamma_h = 30$ and $\gamma_b = 5$. With the parameter choices, the average excess return of the local stock is 3 percent with $i = 0$. The risk aversion coefficients are high compared with most of the literature, since we do not embed additional features that enable us to have a sizable risk premium. Most asset pricing studies calibrate and estimate IES being greater than 1 (e.g., Schorfheide, Song, and Yaron (2018) estimate IES=2). In our model, we require a substantial heterogeneity in IES across agents and choose $\psi_h = 1.2$ and $\psi_b = 3$.

The effective time discount rates of both agents are $\rho + \kappa = 0.025$. The relative preference over the nontraded good $\alpha > \frac{1}{2}$ captures a bias of preference towards the local nontraded good. $\alpha = 0.975$ captures a substantial consumption home bias. The elasticity of substitution across goods θ takes a small number of 0.5. It is consistent with a number of studies in the international macroeconomics literature, such as Stockman and Tesar (1995) and Corsetti, Dedola, and Leduc (2008).

Panel B lists the parameters for endowment processes. The dividend of nontraded good follows a geometric Brownian motion with an average growth rate of 2.5 percent and a volatility of 2.5 percent. The ratio of the traded good over the nontraded good is a constant $(\frac{1-\alpha}{\alpha})^{\theta} = 0.160$, so that $Q = 1$ under autarky.

Panel C shows the parameters on the foreign bond return process. The instantaneous return r^* is equal to 2.36 percent, while σ_q^* is equal to 2 percent.

Panel D reports the crucial parameter that determines the cost of leverage, λ. λ determines how much cash is needed for each unit of borrowing. We set λ as a common parameter across all countries and calibrate it to the average ratio of liquid assets over total assets in the banking systems of the major G10 countries. With $\lambda = 0.2$, countries with different nominal interest rates have substantial differences in their costs of leverage, while bankers still have incentives to lever up.

When we introduce stochastic interest rate, we set its persistence $1 - \zeta = 0.9$. Nominal interest rate is very persistent in the data, while we choose a relatively mild number. The unconditional means of nominal interest rates change from 1 percent to 4 percent.

Lastly, in Panel E, we report the parameters that keep the economy stationary. We set $\bar{\omega} = 0.95$ so that the redistribution of wealth favors households. $\eta = 0.2$ ensures a stationary distribution of χ in the simulation.

3.2 Bank Leverage, Stock Return, and Real Exchange Rate

We study a cross-section of economies that differ only in nominal interest rates, ranging from $i = 0$ to $i = 0.05$. We illustrate the *liquidity-leverage* mechanism by analyzing the solutions of bank leverage, local stock return, exchange rate, and currency risk premium as functions of the endogenous state variables in each economy. We also show impulse responses of various variables to a positive endowment shock in each economy. For the sake of space, we only report results for the two economies with $i = 0$ and $i = 0.05$.

When solving and simulating the model, we introduce a country-specific lump-sum redistribution of wealth between households and bankers so that the ergodic means of ω are similar across countries. Details about simulation are provided in Appendix C. In Appendix D.2, we show the same set of results without the redistribution. The results are qualitatively similar.

3.2.1 Bank Leverage and Stock Return

Nominal interest rates affect bank leverage since they represent the cost of taking leverage. Equation (28) indicates that higher nominal rates reduce risk taking and lead to lower leverage for bankers, as the Panel A of Figure 2 shows. When we compare the two economies, we find that, for every given ω and χ, bank leverage is higher when $i = 0$.

The higher leverage in the $i = 0$ economy makes bankers' wealth more exposed to the endowment shock due to the following amplification mechanism. A positive endowment shock increases bankers' wealth share, which pushes up the local stock price and further increases their wealth share. The magnitude of amplification increases with the bankers' leverage choice. Therefore, as shown in Panel B of Figure 2, the low-interest-rate economy's ($i = 0$) local stock price exposure to the endowment shock (σ_{sx}) is larger.

We note that σ_{sx} displays a hump shape with respect to households' wealth share ω, since the amplification is strong when bankers have enough wealth to affect the local stock price while they take a high enough leverage. Panel C of Figure 2 shows that the risk premium of the local stock is an asymmetric hump shape along ω. When the endogenous volatility (σ_{sx}) spikes, the risk premium also spikes. When endogenous volatility σ_{sx} is close to the endowment volatility (σ_x), the risk premium is higher when wealth is accumulated in more risk-averse households, or ω being close to 1.

The impulse response functions in the two upper panels of Figure 4 show the different responses of local stock returns and household wealth shares to the same positive endowment shock in the two economies. The blue solid line shows the response of the local stock return and households' wealth share in the $i = 0$ economy, while the red dashed line shows the responses in the $i = 0.05$ economy. The local stock return rises by 8 percent in the $i = 0$ economy on impact, while the 3-percent increase in the $i = 0.05$ economy is much milder. Consequently, household wealth share ω drops by 3 percent in the $i = 0$ economy, larger than the 0.5 percent drop in the $i = 0.05$ economy.

3.2.2 Exchange Rate and Currency Risk Premium

This section discusses the exchange rate responses to the endowment shock, and the associated currency risk premium in the two economies with $i = 0$ and $i = 0.05$. As we show in section 3.2.1, bankers' wealth share increases in response to a positive endowment shock. Since bankers' have higher IES than households do, the low-interest-rate economy is more desired to save with bankers' higher wealth share in good times. Therefore, the demand for foreign asset increases sharply and the foreign currency strongly appreciates. On the contrary, the magnitude of foreign appreciation for the high-interest-rate economy is much milder.

Panel A of Figure 3 shows the exchange rate response to a positive endowment shock, σ_{qx}. The exchange rate response mirrors the response of local stock returns, which is a hump-shape with ω. When we compare the $i = 0$ and $i = 0.05$ economies, we find that the foreign appreciation is larger in the low-interest-rate economy, since wealth redistribution between households and bankers is stronger. The same result can be seen from the lower panel of Figure 4, which shows the impulse response of foreign appreciation to a positive endowment shock.

The Euler equation (34) shows that the currency risk premium depends on the covariance of exchange rate movement with the state price densities for both investors, which are largely driven by σ_{sx}. Because the low-interest-rate countries have higher stock returns and sharply depreciated exchange rates in good times, investors require a higher return to borrow low-interest-rate currencies to invest abroad. In other words, low-interest-rate currencies are good hedges to endowment shocks.

Panel B in Figure 3 shows the currency risk premium of investing in the common foreign bond in the two economies. The currency risk premium also displays a hump shape along ω, while it is larger in the low-interest-rate country with $i = 0$. In Panel C of Figure 3, we report the ergodic distribution of the two endogenous state variables.

3.3 Simulation

We simulate a cross-section of six economies with fixed but different levels of nominal interest rates, ranging from 0 to 5 percent with an incremental step of 1 percent. We report the ergodic mean of different variables for each economy in Panels A to C of Table 2 and confirm the implications discussed above.

The nominal interest rates affect bankers' leverage choices as they essentially represent the cost of taking leverage. The average bankers' leverage (w_h^b) decreases with the nominal interest rate, from 1.946 to 1.373. We are not able to replicate the high bank leverage in the data quantitatively. From the market clearing condition for the local stock, we obtain:

$$w_b^h = \frac{1 - \frac{NFA}{W} - \omega w_h^h}{1-\omega} < \frac{1 - \frac{NFA}{W}}{1-\omega} \tag{43}$$

As $\frac{NFA}{W}$ is very close to 0, the largest possible bank leverage is $\frac{1}{1-\omega}$. Suppose ω fluctuates between 0.4 and 0.7, the maximum possible bank leverage is 3.3. Despite the quantitative discrepancy, the model still captures the qualitative heterogeneity in bank leverage across economies with different levels of nominal interest rates.

Due to bankers' high leverage (w_h^b) and the strong amplification mechanism, low-interest-rate economies have large local stock return exposure (σ_{sx}) endogenously and thus high risk premia ($\mu_s - r$). In the simulation, the risk premium for the local stock is as large as 3.140 percent when $i = 0$, and declines to 1.791 percent when $i = 0.05$. Due to higher leverage and higher risk premium for the local stock, the $i = 0$ economy has a smaller ergodic mean of ω than the $i = 0.05$ economy.

The real interest rates (r) are mainly determined by the wealth distribution across households and bankers in these economies. If households' wealth share is high, the real interest rate is high because households have lower IES. Countries with lower nominal interest rates have lower households' wealth share on average, so they tend to have low real interest rates as well. The average real interest rate ranges from 0.756 percent when $i = 0$ to 2.392 percent when $i = 0.05$. This is consistent with the data that low-nominal-rate economies also tend to have low real rates.

As for the exchange rates and currency risk premia, the exchange rate exposure to endowment shock (σ_{qx}) is 5.425 percent for the $i = 0$ economy and 1.215 percent when $i = 0.05$. A positive exposure means a foreign depreciation and domestic appreciation in bad times. A large appreciation of the low-interest-rate currency in bad times makes it a good hedge. Thus, investors require a higher risk premium to borrow it and invest abroad. The currency risk premium is 2.061 percent in the $i = 0$ economy and 0.457 percent in the $i = 0.05$ economy. The spread is 1.604 percent on average, which is close to its empirical counterpart of 2.161 percent shown in Table 5.

3.3.1 Factor Structures of Asset Returns

After examining the unconditional moments of the key variables, we explore the rich factor structures of asset returns implied by our model. In the simulation, all countries experience common shocks. The asset return factor structures in our simulated data are reported in Panel D of Table 2.

We first look at the factor structure of currency returns. Lustig et al. (2011) find that the differences in expected returns of currency portfolios can be explained by their heterogeneous exposures to a "carry risk factor," which is defined as the spread between returns in the highest-interest-rate currencies and the lowest-interest-rate currencies. Low-interest-rate currencies (long position) are less (more negatively) exposed to the "carry risk factor."

We compute the analog of the "carry risk factor" in our model as $dR_f|_{i=0} - dR_f|_{i=0.05}$. It essentially measures the magnitude of the endowment shock. Low-interest-rate currencies depreciate in good times while high-interest-rate currencies appreciate. Therefore, the "carry risk factor" is large when the endowment shock is positive and large. The return exposure (β_{FX}) is computed as the regression coefficient of dR_f in each economy on the risk factor. dR_f is the return to borrowing the domestic currency and investing in the common foreign asset. A larger β_{FX} for currency i means that currency depreciates more in response to a positive endowment shock. The first row in Panel D shows that β_{FX} monotonically decreases with the nominal interest rate, consistent with the empirical finding of Lustig et al. (2011).

Second, we examine the factor structure of stock returns. In a recent paper, Colacito et al. (2018) identify a factor structure of stock valuations across countries. They find that low-interest-rate countries' stocks have higher exposures to the cross-sectional average. We calculate the exposure of stock return (dR_s) to the cross-sectional average ($\overline{dR_s}$) and find that β_s monotonically decreases with nominal interest rates. The intuition is straighforward: when the same shock hits low-interest-rate countries, their local stock returns increase more due to high bank leverage. Therefore, our model can also replicate Colacito et al. (2018)'s empirical finding.

Finally, we compute the exposures of currency returns (dR_f) to average stock return ($\overline{dR_s}$) and bank wealth portfolio return ($\overline{w_h^b dR_s}$) across countries, $\beta_{FX,s}$ and $\beta_{FX,b}$ respectively. Both the average stock return $\overline{dR_s}$ and the average bank wealth portfolio return $\overline{w_h^b dR_s}$ are measures of the magnitude of the common endowment shock[10]. Therefore, both $\beta_{FX,s}$ abd $\beta_{FX,b}$ decrease with the interest rate. In section 4.3, we empirically test this implication by measuring return to bankers' wealth with the banking sector stock return in each country.

[10] We ignore the return on the foreign bond since it is very small.

3.3.2 Time-varying Carry Trade Beta

In this section, we discuss a distinct feature of the model on the time variation of currency carry trade exposures (betas) to the average stock returns ($\beta_{FX,s}$). The dynamics of the carry trade beta were first noted by Lustig et al. (2008), that they are particularly high during the crisis. As there is no well-defined notion of "crisis" in our model, we explore the correlation between the carry trade return $\beta_{FX,s}$ (the portfolio return is computed as $dR_f|_{i=0} - dR_f|_{i=0.05}$) and the volatility of the average stock return.

In our model, $\beta_{FX,s}$ is positively related to the average stock return volatility. The intuition is simple: the exchange rate movement tracks stock return especially when the amplification is strong. This is also when the endogenous stock volatility is high. In the simulated data, we calculate the correlation between $\beta_{FX,s}$ and the average stock return volatility as 0.705. We empirically test this implication in section 4.4.

3.4 Interest Rates and Currency Risk Premia in the Time Series

In previous sections, we compared bank leverage and currency risk premia across countries with heterogeneous but fixed nominal interest rates. In this section, we examine our model implications on the time-series relationship between interest rates and currency risk premia. To study the time-series relationship, we introduce a stochastic nominal interest rate process of equation (10). Different countries have different unconditional means (i_0), ranging from 1 percent to 4 percent.

A sizable body of literature has documented and explained the positive regression coefficient of currency returns on interest rate differentials, β_{FP}. In Panel A to C of Figure 5, we plot the solutions of bank leverage (w_h^b), exchange rate exposure (σ_{qx}), and currency risk premium ($\mu_f - r$) as functions of households' wealth share (ω) and nominal interest rate (i) for the $i_0 = 0.01$ economy[11]. Since there are three state variables with stochastic interest rates, we fix $\chi = 0$ when plotting the solutions. From the three panels, we see that the risk premium of investing abroad declines with i. This is because when i increases, its exchange rate becomes less of a hedge due to the decreased leverage choice of bankers.

We run the following regressions with the simulated data in each economy:

$$rx_{r,t+1} = \alpha - \gamma_r i_t + \epsilon_{t+1} \tag{44}$$

$$rx_{i,t+1} = \alpha - \gamma_i i_t + \epsilon_{t+1} \tag{45}$$

We assume the foreign interest rate is an exogeneous constant, so that i_t^* is abstracted from the right-hand side of both regressions. The left-hand side of equation (44) is the return of investing abroad in excess of the real interest rate, while the left-hand side of equation (45) is the return of investing abroad in excess of the nominal interest rate.

[11]For other values of i_0, the solutions are very similar.

Panel E of Table 3 show γ_r and γ_i for the four economies. $\gamma_r(\gamma_i)$ is the regression coefficient of the excess currency returns in real (nominal) terms on the interest rate differentials. Both coefficients in the four economies are positive, consistent with the empirical findings of the literature. Quantitatively, γ_r is small while γ_i is about the same magnitude as in the data. In our model, there is no stickiness in price setting, so that a nominal rate rise is mostly reflected in an increase in inflation while the real interest rate responds only by a small magnitude induced by the decline of bankers' wealth share.

Panel A to D of the table are analogous to Table 2. In the cross-section of economies with stochastic interest rates, low-interest-rate countries have high bank leverage and their currencies appreciate the most in bad times. Therefore, investors require a positive premium to borrow these currencies and invest abroad.

Next, we study the impulse response of the currency risk premium of investing abroad to an unexpected rise in the nominal interest rate in each economy. Mueller et al. (2017) find that after the Fed unexpectedly raises the interest rate, the subsequent return of foreign currency investment declines. Panel D of Figure 5 displays the impulse responses of currency risk premia (in real terms) for the four economies to the same shock to the nominal interest rate. In all four economies, the currency risk premia decrease after an unexpected increase in the nominal interest rate. The currency risk premia for the four economies decline by about 3-4 basis points in response to an unexpected interest rate rise of $\sigma_i = 17.4$ basis points.

Since Mueller et al. (2017) use high-frenquency data in their empirical study, it is hard to map our model implication to the data quantitatively. Therefore, we only make qualitative claims on the impulse response of currency risk premium to nominal interest rate shocks.

3.5 Additional Results

3.5.1 Liquidity Premium and CIP Deviation

In this subsection, we show that our model can naturally generate deviations from covered interest rate parity (CIP). CIP is a no-arbitrage condition, which states that if an investor borrows the dollar and invest in a foreign currency while hedging away the exchange rate risk, the return should be 0.

We define $i_t^*, i_t^\$$ as the interest rate in the foreign currency and the dollar, q_t as the spot exchange rate of foreign currency in dollars, and f_t as the forward rate. The return to the arbitrage, $-x_t$ (x_t is called "basis"), can be expressed as:

$$-x_t = -i_t^\$ + q_t + i_t^* - f_t \tag{46}$$

Under CIP, $x_t = 0$. According to Du et al. (2018b), after the recent financial crisis in 2008, the basis (x_t) has been negative. Our model sheds light on the liquidity friction that could potentially lead to what we observe in the data[12].

Suppose only the bankers have access to the CIP arbitrage. Each unit of safe dollar liabilities is subject to a withdrawal need of $\frac{\lambda}{1+\lambda}$, while $\frac{\tilde{\lambda}}{1+\lambda}$ fraction of the foreign asset can be liquidated costlessly. The foreign asset payoff is $i_t^{\$} - x_t$. According to equation (15), we obtain:

$$x_t = (\tilde{\lambda} - \lambda) i_t^{\$} \tag{47}$$

Eqution (47) shows that if $\tilde{\lambda} < \lambda$, $x_t < 0$. Intuitively, if dollar asset is more liquid than the foreign asset, investors require a positive premium to conduct the CIP arbitrage above.

Next we explore into the quantitative implication of CIP deviation on the relative liquidity of dollar and foreign safe assets. Du et al. (2018b) document an average currency basis (x_t) of -25 basis points, while one third of the basis is possibly caused by liquidity concerns[13]. We plug in $x = -8bp, \lambda = 0.2$, and $i^{\$} = 50bp$, which is equal to the time-series average of US LIBOR rate between 2010 and 2016. Then we obtain $\tilde{\lambda} = 0.04$, which implies a substantial difference in liquidity between dollar and foreign safe assets.

3.5.2 Liquidity Premium and Currency Risk Premium

In this subsection, we discuss the interaction between the liquidity premium amd currency risk premium implied by our model. In a recent paper, Jiang et al. (2018) uncover a positive correlation between the liquidity premium of dollar liquid assets and its currency premium component in a VAR-based decomposition. A slightly extended version of our model can account for this empirical observation. Let us take the stand of a foreign investor, who holds both domestic and dollar liquid assets that are imperfect substitutes with the aggregator,

$$L = \left(L_d^{\frac{\epsilon-1}{\epsilon}} + L_{\$}^{\frac{\epsilon-1}{\epsilon}} \right)^{\frac{\epsilon}{\epsilon-1}} \tag{48}$$

L is the total liquid asset holding. L_d is the holding of domestic liquid asset, and $L_{\$}$ is the holding of dollar liquid asset.

The banker chooses the optimal amount of local and dollar liquid assets by minimizing the cost of liquidity:

$$\min_{L_d, L_{\$}} L_d lp + L_{\$} lp_{\$} \tag{49}$$

$$s.t. : L = \left(L_d^{\frac{\epsilon-1}{\epsilon}} + L_{\$}^{\frac{\epsilon-1}{\epsilon}} \right)^{\frac{\epsilon}{\epsilon-1}} \tag{50}$$

$lp, lp_{\$}$ are liquidity premia of the local and dollar liquid asset, respectively. With cash in the

[12] In Du et al. (2018b), the authors explain CIP deviations with changes in regulations after the financial crisis, such as the leverage ratio requirement and other regulations including liquidity.

[13] See Table VI of Du et al. (2018b). Another major reason that leads to CIP deviation is the change in non-risk-weighted leverage ratio requirement.

local country, the liquidity premium for local liquid asset (lp) is equal to the nominal interest rate i. We assume (i) $L_\$$ is supplied with perfect elasticity; (ii) the domestic monetary authority and government control the supply of L_d, and (iii) the dollar liquidity premium ($lp_\$$) is exogenously given. The optimal holdings of dollar liquidity is given by:

$$L_\$ = L_d \left(\frac{lp}{lp_\$} \right)^\epsilon \tag{51}$$

A rise in $lp_\$$ implies less of the dollar liquidity holding ($L_\$$). The total cost of liquidity is given by:

$$L_d lp + L_\$ lp_\$ = L_d lp + L_d lp^\epsilon lp_\$^{1-\epsilon} \tag{52}$$

With $\epsilon > 1$ when the two liquid assets are substantially substitutable, a rise in the dollar asset liquidity premium is associated with a drop in the total cost of liquidity. For the bankers, it is equivalent to a drop in the nominal interest rate, so that the risk premium to invest in dollar increases.

3.6 Model Implications

We conclude this section by summarizing the three major model implications, around which our subsequent empirical analysis is centered.

The first implication is straightforward: countries with lower nominal interest rates tend to have higher bank leverage and lower currency returns.

The second implication states the cyclicality of exchange rates: low-interest-rate currencies depreciate in good times relative to high-interest-rate ones. To highlight the role of intermediaries, we measure the "good times" with average bank stock returns in all countries.

Third, our model implies that carry trade return's comovement with the average stock return is time-varying, and it increases with the stock market volatility.

4 Empirical Analysis

4.1 Data

We mainly use three sets of data in our empirical analysis: spot and forward exchange rates, country-level banking sector balance sheet, and country-level stock return index of the banking sector. The data cover 22 advanced countries: Australia, Austria, Belgium, Canada, Denmark, Finland, Euro, France, Germany, Greece, Ireland, Italy, Japan, Netherlands, New Zealand, Norway, Portugal, South Korea, Spain, Switzerland, Sweden, and the UK.

The spot and one-month forward exchange rate data are from standard sources of Datastream at the monthly frequency from November 1983 to December 2016, following Lustig et al. (2011).

We take the mid-price of the forward and spot quotes on the last day of each month.

We calculate each country's banking sector capital ratio (the inverse of leverage, in percentage) using the aggregate banking data from SNL Financial, originally provided by Economist Intelligence Unit (EIU). Capital ratio is calculated as the ratio of total equity capital over assets. The bank balance sheet data are at the annual frequency from 1990 to 2015. Total assets and equity capital are simple sum of those collected from reporting banks. After 1999, all countries using the Euro are replaced with a single time series of Euro spot and forward rate; the bank capital ratio for the euro area is the average across these countries.

The country-level banking sector stock total return indices are from Datastream from January 1983 to December 2016, at the monthly frequency. The dataset includes an index for the Euro area bank stock returns, which are used after 1999 for the Euro area.

We also use each country's GDP and inflation as control variables. Both variables are obtained from the World Bank website at the annual frequency.

4.2 Interest Rate, Bank Leverage, and Currency Return

4.2.1 Panel Regression

Using panel regressions, we show that countries with lower interest rates have lower bank capital ratio (higher leverage) and lower currency returns. Since we do not attempt to make causal statement from our regression results, it does not matter whether we use the interest rate as a regressor or a regressant. We regress interest rate[14] and currency return on the bank capital ratio.

The panel regression is conducted in the two-step Fama-MacBeth procedure. First, we run a cross-sectional regression of forward discount and currency return on bank capital ratio and get a regression coefficient for each month. The Fama-MacBeth estimator is the simple average of these regression coefficients across time, while standard errors are calculated after adjusting for possible serial correlations.

The regression results are shown in Table 4. The left panel reports the regression coefficients of the forward discount on the bank capital ratio, while the right panel replaces the forward discount with the currency return. In column (1) of the left panel, the coefficient of forward discount on the bank capital ratio is 0.463, being significantly positive. In the cross-section, a one percent increase of the bank capital ratio is associated with a 46.3 basis point increase in the forward discount per annum. The same is true for the currency return. A one percent increase of the bank capital ratio is associated with a 27.9 basis point increase in the currency return. In the data, average bank capital ratio varies from 3 percent to 10 percent, which translates into a 3.24 percent difference in the forward discount and 1.95 percent difference in the currency return.

[14] Under the covered interest rate parity, forward discount is equal to the difference between country specific interest rate and US interest rate. Even though CIP is deviated after the crisis, the deviation is small in magnitude relative to interest rate differentials. In this section, "forward discount" and "interest rate differential" are used interchangably.

In column (2) of both panels, we control for the inflation (percentage change of consumer price index) in each country. The coefficient for forward discount is smaller in magnitude, but still significant. Unsurprisingly, inflation accounts for a big fraction of cross-sectional difference in the nominal interest rate across countries (R^2 increases from 0.134 to 0.394). However, the coefficient of the currency return stays stable at 0.204 while being statistically significant, and the R^2 increase is mild, from 0.124 to 0.265.

In column (3), we control for each country's log GDP (country size), which Hassan (2013) considers as an important determinant of the interest rate and currency return. In column (4) we control for both inflation and country size. Our results are robust to these controls.

The regressions in Table 4 include 22 advanced economies. A natural question is whether the relationship also holds for the emerging economies. We show the regression results for both advanced and emerging economies in Appendix E.2. After including the emerging economies, the relationship between the interest rate and bank capital ratio is positive, similar to the advanced economies. The regression coefficient of the currency return on bank capital ratio is also positive without controlling for inflation. However, after controlling for inflation, the regression coefficient becomes insignificant and sometimes even negative. The result suggests that inflation plays a more important role in emerging economies than in advanced economies. In the rest of the empirical analysis, we restrict our attention to the set of advanced economies.

4.2.2 Portfolio Sorting

In this section, we show the relevance of bank leverage in currency pricing by sorting currencies based on each country's bank leverage. We sort all available currencies into three portfolios with annual rebalance, since our banking sector balance sheet variables are only available at the annual frequency.

Panel A in Table 5 shows the characteristics of leverage sorted currency portfolio returns. Portfolio 1 contains currencies with the highest banking sector leverage (such as Japan) and portfolio 3 contains those with the lowest banking sector leverage (such as Australia). The average average forward discount increases from 0.05 percent to 1.669 percent per annum. The bank capital ratio rises from 4.476 percent in portfolio 1 to 7.612 percent in portfolio 3. The average currency return monotonically increases from -0.687 percent in portfolio 1 to 1.465 percent in portfolio 3. The return spread between the lowest leverage countries and the highest leverage countries is 2.152 percent on average, with a Sharpe ratio of 0.389.

In Panel B, we sort currencies based on their unconditional average forward discount, measured by the full sample average of each country. Portfolio rebalancing is also at the annual frequency. The lowest interest rate currencies have a -0.734 percent average forward discount, while the highest ones have an average of 2.540 percent. The forward discount differential between portfolio 3 and portfolio 1 is 3.274 percent, which is about twice as large as what we obtained in Panel A. The bank capital ratio increases from low-interest-rate countries to high-interest-rate countries with a spread of 1.224 percent, about one third of what we obtain when sorting on bank leverage. The return spread between portfolio 3 and 1 is 2.161 percent per annum with a Sharpe ratio of 0.343. The average return spread and Sharpe ratio is similar to those in Panel A.

In Panel C, we sort the currency portfolios based on the previous year's average forward discount. The pattern of forward discount, bank capital ratio, and excess return are similar to Panel B while the return spread is larger. However, the capital ratio spread is smaller. The return characteristics of the leverage sorted portfolios in Panel A are closer to the unconditional forward discount sorted portfolios in Panel B. This indicates that the cross-sectional variation in bank leverage largely captures the unconditional interest rate heterogeneity, while it does not completely reflect the time-series variations.

There are two reasons that make bank leverage contain less information of currency return than interest rate. First, as our model suggests, bank leverage increases with bankers' wealth share, while the relation between the currency risk premium and bankers' wealth share is nonmonotonic. Second, the bank balance sheet variables are hard to measure accurately, which also adds noise to our portfolio sorting. Despite these disadvantages, we still find similarities in currency portfolios sorted on the bank leverage and the forward discount, validating our hypothesis that bank leverage is an important driver of currency returns.

4.2.3 Asset Pricing Test

In this subsection, we show the pricing power of the risk factor constructed from portfolios sorted on bank leverage. The risk factor (Lev-factor) is the spread between portfolio 3 and portfolio 1 in Table 5 Panel A. We first examine the correlation of Lev-factor with conventional "carry risk factor" in the literature, defined as the spread between portfolio 3 and portfolio 1 in Panel B and C of Table 5. We call these two factors "unconditional carry-factor" and "conditional carry-factor," respectively. In Table 6, we regress the unconditional and conditional carry-factor on the Lev-factor. In the first column, the sensitivity of the unconditional carry-factor to the Lev-factor is 0.655, with the unexplained residual of 0.752 percent and an R^2 of 0.332. The two are highly correlated, and the unexplained residual is statistically insignificant. The second column reports the regression coefficients for the conditional carry-factor. The coefficient is still significantly positive but smaller in magnitude (0.444), and the unexplained residual is 2.460 percent and statistically significant. The R^2 is 0.119, much smaller than the regression R^2 with the unconditional carry-factor. The comparison further verifies that the Lev-factor better captures the variations of the unconditional forward discount sorted portfolios than the conditional forward discount sorted ones.

Next we conduct an asset pricing test by using the six portfolios sorted on bank leverage and forward discount (unconditionally) as test assets. Panel A of Table 7 reports the first step Fama-MacBeth estimation results for the six portfolios. For the leverage sorted portfolios, the exposure to the Lev-factor monotonically increases from -0.444 for portfolio 1 to 0.556 for portfolio 3. For the forward discount sorted portfolios, the exposure to the Lev-factor also monotonically increases, from -0.228 for the portfolio with the lowest interest rate, to 0.427 for the portfolio with the highest interest rate. Heterogeneous exposures to the Lev-factor accounts for the cross-sectional variations in expected returns of these portfolios.

In Panel B of Table 7, we report the estimates of the risk price using both the Fama-MacBeth method and the GMM method. When using GMM, the pricing kernel is written as a linear factor model following Lustig et al. (2011):

$$m = 1 - bf \tag{53}$$

where f is the factor, and b is the price of risk. We use Hansen and Jagannathan (1997)'s scale-invariant weight matrix in the GMM estimation. We obtain similar positive estimates of the price of risk using these two methods. They are close to the unconditional mean of the Lev-factor. The risk price is statistically significant for both methods.

4.3 Currency Returns and Bank Stock Returns

In this section, we test the second implication of the model—that low-interest-rate currencies are less (more negatively) exposed to average bank stock return. The cross-sectional average measures the common "good times" for all countries instead of the idiosyncratic ones. We use the bank stock return to highlight the role of intermediaries in driving exchange rate dynamics. In Appendix E.3, we show similar results with the average country MSCI stock return indices.

4.3.1 Procyclical Carry Trade

First, we calculate the sensitivities of exchange rates to the average bank stock return (β_{bank}) for the G10 currencies and plot them against their average forward discounts in the upper panel of Figure 6. The two variables are highly correlated. Countries such as Japan and Switzerland have low forward discounts and their exchange rates are countercyclical. On the other hand, countries like Australia and New Zealand have high forward discounts and procyclial exchange rates.

In the lower panel of Figure 6, we replace the average forward discount with average bank capital ratio. The result is similar—that β_{bank} increases with the average bank capital ratio across countries.

To see the procyclicality of carry trade returns more clearly, we regress the returns to three "carry trade" strategies on the average bank stock return. The first strategy borrows the Japanese yen and invests in the Australian dollar, "AUD-JPY." The second strategy borrows the Swiss Franc and invests in the New Zealand dollar, "NZD-CHF." These are the typical currency pairs involved in currency carry trades. The third strategy borrows currencies with unconditionally low forward discounts and invests in those with high forward discounts, "unconditional carry." All the three slope coefficients are significantly positive. A one percent increase in the average bank stock return is associated with a 30 basis point increase in the "AUD-JPY" strategy, a 25.1 basis point increase in the "NZD-CHF" strategy, and a 15.5 basis point increase in the unconditional carry strategy.

4.3.2 Asset Pricing Test

In this section, we test whether heterogeneous exposures to the average bank stock return account for the cross-sectional variation in expected returns of currency portfolios. Again, we focus on the portfolios sorted on unconditional forward discounts.

In the top row of Table 9, we report the average returns to the three currency portfolios, from 0.780 percent for the currencies with the lowest interest rates to 2.877 percent for the currencies with the highest interest rates. Panel A shows the first-step Fama-MacBeth regression results. Exposures to the average bank stock return monotonically increase from -0.005 to 0.15. In panel B, we estimate the price of risk using the Fama-MacBeth and the GMM methods, and obtain similar estimates. Our asset pricing test indicates that the bank stock return is one candidate risk factor that can explain the cross-sectional variation in currency expected returns. However, the α's are large, so that a single factor of the bank stock return is not enough to price the currency portfolios.

4.4 Time-varying Carry Trade Beta

In this section, we examine the last implication on the relationship between the carry trade beta with average stock return $\beta_{FX,s}$ and the stock market volatility. We average the country-level MSCI stock return indices with equal weights and obtain a risk factor of the average stock return, in the similar way as in section 4.3. We compute $\beta_{FX,s}$ in every five-year rolling window for the long-short portfolio sorted on unconditional forward discount. The stock market volatility is measured as the realized volatility of the average stock return. Figure 7 plots the relationship between the stock return volatility (on the horizontal axis) and $\beta_{FX,s}$ (on the vertical axis). It is clear that $\beta_{FX,s}$ increases with the stock return volatility, with a statistically significant regression coefficient of 6.64. This implies a one percent increase in the stock market volatility is associated with an increase of 0.0664 in $\beta_{FX,s}$ for the long-short portfolio on average. The correlation between the currency carry trade beta and the stock market volatility in the data is 0.645, while the correlation in the model simulated data is 0.705.

5 Conclusion

This paper provides an intermediary-based explanation of the currency risk premium associated with carry trade with a *liquidity-leverage* channel. Countries differ in nominal interest rates. Bankers in low-interest-rate countries take high leverage for the low cost of holding liquid assets, which translates into a large drop in their wealth along with a negative shock. Due to the higher IES of bankers than of households, the total demand of foreign asset declines in bad times and the domestic currency appreciates. Therefore, investors require a positive risk premium to borrow low-interest-rate currencies. With the same *liquidity-leverage* channel, our model can account for the decline (rise) of foreign currency risk premium in response to an unexpected interest rate rise (cut), as well as the time series positive correlation of interest rate differential and subsequent return to invest abroad. Our model implies deviations from covered interest rate parity when safe assets differ in liquidity, and delivers the positive relation between liquidity premium and currency risk premium of dollar assets. Empirically, our evidence is consistent with the major model implications. First, low-interest-rate countries tend to have high bank leverage and low currency returns. This is the key mechanism of the model. Second, carry trade is procyclical with respect to the average bank stock return. Finally, comovement of the carry trade return and average stock return increases with the stock market volatility.

References

T. Adrian, E. Etula, and T. Muir. Financial intermediaries and the cross-section of asset returns. *The Journal of Finance*, 69(6):2557–2596, 2014.

T. Adrian, E. Etula, and H.-S. Shin. Risk appetite and exchange rates. Technical report, Staff Report, Federal Reserve Bank of New York, 2015.

F. Alvarez, A. Atkeson, and P. J. Kehoe. Time-varying risk, interest rates, and exchange rates in general equilibrium. *The Review of Economic Studies*, 76(3):851–878, 2009.

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

D. K. Backus, F. Gavazzoni, C. Telmer, and S. E. Zin. Monetary policy and the uncovered interest parity puzzle. *Working Paper*, 2013.

R. Bansal. An exploration of the forward premium puzzle in currency markets. *The Review of Financial Studies*, 10(2):369–403, 1997.

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

M. Baxter, U. J. Jermann, and R. G. King. Nontraded goods, nontraded factors, and international non-diversification. *Journal of International Economics*, 44(2):211–229, 1998.

G. Bekaert. The time variation of risk and return in foreign exchange markets: A general equilibrium perspective. *The Review of Financial Studies*, 9(2):427–470, 1996.

M. J. Brennan and Y. Xia. International capital markets and foreign exchange risk. *The Review of Financial Studies*, 19(3):753–795, 2006.

V. Bruno and H. S. Shin. Capital flows and the risk-taking channel of monetary policy. *Journal of Monetary Economics*, 71:119–132, 2015.

N. Coeurdacier. Do trade costs in goods market lead to home bias in equities? *Journal of international Economics*, 77(1):86–100, 2009.

N. Coeurdacier and H. Rey. Home bias in open economy financial macroeconomics. *Journal of Economic Literature*, 51(1):63–115, 2013.

R. Colacito and M. M. Croce. International asset pricing with recursive preferences. *The Journal of Finance*, 68(6):2651–2686, 2013.

R. Colacito, M. M. M. Croce, F. Gavazzoni, and R. Ready. Currency risk factors in a recursive multicountry economy. *The Journal of Finance, Forthcoming*, 2018.

G. Corsetti, L. Dedola, and S. Leduc. International risk sharing and the transmission of productivity shocks. *The Review of Economic Studies*, 75(2):443–473, 2008.

G. Dell'Ariccia, L. Laeven, and G. A. Suarez. Bank leverage and monetary policy's risk-taking channel: evidence from the united states. *The Journal of Finance*, 72(2):613–654, 2017.

M. B. Devereux and A. Sutherland. Country portfolios in open economy macro-models. *Journal of the european economic Association*, 9(2):337–369, 2011.

I. Drechsler, A. Savov, and P. Schnabl. A model of monetary policy and risk premia. *The Journal of Finance*, 73(1):317–373, 2018.

W. Du, J. Im, and J. Schreger. The us treasury premium. *Journal of International Economics*, 112:167–181, 2018a.

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

D. Duffie and L. G. Epstein. Stochastic differential utility. *Econometrica*, pages 353–394, 1992.

E. F. Fama. Forward and spot exchange rates. *Journal of Monetary Economics*, 14(3):319–338, 1984.

X. Fang and Y. Liu. Volatility, intermediaries and exchange rates. 2018.

E. Farhi and X. Gabaix. Rare disasters and exchange rates. *The Quarterly Journal of Economics*, 131(1):1–52, 2015.

J. Favilukis and L. Garlappi. The carry trade and uncovered interest parity when markets are incomplete. 2017.

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

F. Guvenen. A parsimonious macroeconomic model for asset pricing. *Econometrica*, 77(6):1711–1750, 2009.

V. Haddad and T. Muir. Do intermediaries matter for aggregate asset prices? Technical report, UCLA working paper, 2017.

L. P. Hansen and R. Jagannathan. Assessing specification errors in stochastic discount factor models. *The Journal of Finance*, 52(2):557–590, 1997.

T. A. Hassan. Country size, currency unions, and international asset returns. *The Journal of Finance*, 68(6):2269–2308, 2013.

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

B. Hollifield and A. Yaron. The foreign exchange risk premium: Real and nominal factors. *Manuscript. Carnegie Mellon University*, 2003.

O. Itskhoki and D. Mukhin. Exchange rate disconnect in general equilibrium. Technical report, National Bureau of Economic Research, 2017.

U. J. Jermann. International portfolio diversification and endogenous labor supply choice. *European Economic Review*, 46(3):507–522, 2002.

Z. Jiang. Fiscal cyclicality and currency risk premium. *Working Paper*, 2018.

Z. Jiang, A. Krishnamurthy, and H. Lustig. Foreign safe asset demand and the dollar exchange rate. *NBER Working Paper*, 2018.

K. K. Lewis. Trying to explain home bias in equities and consumption. *Journal of Economic Literature*, 37(2):571–608, 1999.

H. Lustig and A. Verdelhan. The cross section of foreign currency risk premia and consumption growth risk. *American Economic Review*, 97(1):89–117, 2007.

H. Lustig, N. Roussanov, and A. Verdelhan. Common risk factors in currency markets. *NBER Working Paper*, 2008.

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

M. Maggiori. Financial intermediation, international risk sharing, and reserve currencies. *American Economic Review*, 107(10):3038–71, 2017.

S. Malamud and A. Schrimpf. An intermediation-based model of exchange rates. 2018.

S. Miranda-Agrippino and H. Rey. Us monetary policy and the global financial cycle. 2018.

P. Mueller, A. Tahbaz-Salehi, and A. Vedolin. Exchange rates and monetary policy uncertainty. *The Journal of Finance*, 72(3):1213–1252, 2017.

S. Nagel. The liquidity premium of near-money assets. *The Quarterly Journal of Economics*, 131 (4):1927–1971, 2016.

A. Pavlova and R. Rigobon. Asset prices and exchange rates. *The Review of Financial Studies*, 20 (4):1139–1180, 2007.

A. Pavlova and R. Rigobon. Equilibrium portfolios and external adjustment under incomplete markets. 2012.

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

H. Rey. International channels of transmission of monetary policy and the mundellian trilemma. *IMF Economic Review*, 64(1):6–35, 2016.

R. J. Richmond. Trade network centrality and currency risk premia. *The Journal of Finance, Forthcoming*, 2018.

M. Sandulescu, F. Trojani, and A. Vedolin. Model-free international stochastic discount factors. 2017.

S. Schmitt-Grohé and M. Uribe. Closing small open economy models. *Journal of International Economics*, 61(1):163–185, 2003.

F. Schorfheide, D. Song, and A. Yaron. Identifying long-run risks: A bayesian mixed-frequency approach. *Econometrica*, 86(2):617–654, 2018.

A. Stathopoulos. Asset prices and risk sharing in open economies. *The Review of Financial Studies*, 30(2):363–415, 2016.

S. Stepanchuk and V. Tsyrennikov. Portfolio and welfare consequences of debt market dominance. *Journal of Monetary Economics*, 74:89–101, 2015.

A. C. Stockman and L. L. Tesar. Tastes and technology in a two-country model of the business cycle: Explaining international comovements. *The American Economic Review*, pages 168–185, 1995.

R. Valchev. Bond convenience yields and exchange rate dynamics. 2017.

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

A. Vissing-Jørgensen. Limited asset market participation and the elasticity of intertemporal substitution. *Journal of Political Economy*, 110(4):825–853, 2002.

U. Wiriadinata. External debt, currency risk, and international monetary policy transmission. *Working Paper*, 2018.

Table 1: Parameter Values

Variable	Notation	Value
Panel A: Preference Parameters		
Households' risk aversion	γ_h	30
Bankers' risk aversion	γ_b	5
Households' IES	ψ_h	1.2
Bankers' IES	ψ_b	3
Preference over the nontrade goods	α	0.975
Elasticity of substitution across goods	θ	0.5
Time discount rate	ρ	0.005
Exit rate	κ	0.02
Panel B: Endowment Parameters		
Drift of the dividend process	μ_x	0.025
Volatility of the dividend process	σ_x	0.025
Ratio of endowment	τ	0.160
Panel C: Foreign Return Parameters		
Foreign interest rate	r^*	0.0236
Volatility of US nontraded good price	σ_q^*	0.02
Panel D: Monetary Policy Parameters		
Size of funding shock	λ	0.2
Persistence of the nominal interest rate	ζ	0.1
Diffusion of the nominal interest rate	σ_i	$0.004 \times \sqrt{1-(1-\zeta)^2}$
Panel E: Other Parameters		
Wealth redistribution share	$\bar{\omega}$	0.95
Net foreign asset redistribution	η	0.2

Table 2: Simulation Results for A Cross-section of Economies with Fixed Interest Rates

i	0	0.01	0.02	0.03	0.04	0.05
Panel A: Asset Prices (in percent)						
μ_s	3.896	3.873	3.872	3.930	4.032	4.183
r	0.756	1.678	1.950	1.973	2.093	2.392
$\mu_s - r$	3.140	2.195	1.922	1.957	1.939	1.791
σ_{sx}	8.230	6.533	5.330	4.174	3.684	3.161
σ_{qx}	5.432	3.725	2.904	2.276	1.842	1.225
$\mu_f - r$	2.061	1.150	0.881	0.862	0.752	0.457
Panel B: Portfolio Choices						
w_h^b	1.899	1.872	1.779	1.558	1.445	1.367
w_f^b	-0.035	0.063	0.146	0.187	0.215	0.228
w_h^h	0.254	0.374	0.486	0.613	0.695	0.785
w_f^h	0.024	-0.051	-0.102	-0.134	-0.153	-0.139
Panel C: State Variables						
ω	0.531	0.569	0.594	0.586	0.589	0.626
χ	-0.167	-0.186	-0.212	-0.210	-0.223	-0.221
Panel D: Return Exposures						
β_{FX}	1.160	0.737	0.542	0.396	0.291	0.160
β_s	1.595	1.262	1.028	0.803	0.708	0.605
$\beta_{FX,s}$	1.063	0.732	0.577	0.459	0.377	0.259
$\beta_{FX,b}$	0.605	0.408	0.323	0.258	0.211	0.145

Table 3: Simulation Results for A Cross-section of Economies with Fixed Interest Rates

i_0	0.01	0.02	0.03	0.04
Panel A: Asset Prices (in percent)				
μ_s	3.873	3.867	3.959	3.972
r	1.411	1.534	1.722	2.034
$\mu_s - r$	2.462	2.333	2.237	1.938
σ_{sx}	5.955	5.245	4.517	4.092
σ_{qx}	3.774	3.366	2.815	2.374
$\mu_f - r$	1.487	1.352	1.147	0.779
Panel B: Portfolio Choices				
w_h^b	1.803	1.622	1.553	1.559
w_f^b	0.076	0.138	0.196	0.281
w_h^h	0.402	0.491	0.603	0.673
w_f^h	-0.060	-0.116	-0.145	-0.172
Panel C: State Variables				
ω	0.561	0.542	0.574	0.621
χ	-0.137	-0.146	-0.196	-0.312
Panel D: Return Exposures				
β_{FX}	1.370	1.063	0.649	0.370
β_s	1.195	1.058	0.916	0.832
$\beta_{FX,s}$	0.802	0.729	0.627	0.544
$\beta_{FX,b}$	0.473	0.431	0.365	0.313
Panel E: Time Series Coefficients				
γ_r	0.165	0.199	0.277	0.298
γ_i	1.401	1.446	1.508	1.482

Table 4: Bank capital ratio, forward discount, and currency return

	Forward discount				Currency return			
	(1)	(2)	(3)	(4)	(1)	(2)	(3)	(4)
Capital ratio	0.463**	0.170**	0.366**	0.113**	0.279**	0.204*	0.212	0.208**
	(0.071)	(0.011)	(0.063)	(0.005)	(0.100)	(0.116)	(0.150)	(0.094)
Inflation		0.971**		0.948**		0.435		0.374
		(0.117)		(0.098)		(0.557)		(0.570)
GDP			-0.483**	-0.429**			-0.629**	-0.587**
			(0.031)	(0.031)			(0.111)	(0.025)
R^2	0.134	0.394	0.225	0.468	0.124	0.265	0.203	0.341

Note: Fama-Macbeth regression results of the forward discount (left panel) and the currency return (right panel) on the bank capital ratio (the inverse of leverage, in percentage). In both panels, column (1) report the univariate regression coefficients. Column (2) controls for inflation, column (3) controls for the log GDP (size) of each country, and column (4) controls both inflation and log GDP. Data are monthly including 22 countries, from Jan 1990 to Dec 2016. Annual measures of the bank capital ratio and GDP share are used repetitively for months within a year. Standard errors are Newey-West adjusted with 120 lags. ** indicates statistical significance at 5% level. * indicates statistical significance at 10% level.

Table 5: Currency portfolios

	(1)	(2)	(3)	(3)-(1)
Panel A: Leverage sorted portfolios				
Forward discount	0.050	1.068	1.669	1.619
Bank capital ratio	4.476	5.738	7.612	3.135
Excess return	-0.687	0.182	1.465	2.152
Standard deviation	8.513	9.165	8.711	5.550
Sharpe ratio	-0.081	0.020	0.168	0.388
Panel B: Forward discount sorted portfolios (unconditional)				
Forward discount	-0.734	1.128	2.540	3.274
Bank capital ratio	5.324	5.738	6.548	1.224
Excess return	-0.526	-0.226	1.635	2.161
Standard deviation	7.602	9.738	9.242	6.308
Sharpe ratio	-0.069	-0.023	0.177	0.343
Panel C: Forward discount sorted portfolios (conditional)				
Forward discount	-1.054	0.868	3.250	4.303
Bank capital ratio	5.348	6.035	6.199	0.851
Excess return	-0.952	-0.221	2.462	3.414
Standard deviation	8.271	8.575	10.107	7.141
Sharpe ratio	-0.115	-0.026	0.244	0.478

Note: Panel A reports statistics to the three portfolios sorted on bank leverage. Portfolio 1 includes countries with the highest bank leverage while portfolio 3 includes countries with the lowest bank leverage. Rebalancing is annual. Panel B reports the statistics to the three portfolios sorted on full sample average forward discount. Panel C reports the statistics to the three portfolios sorted on average forward discount in the previous year with annual rebalancing. All numbers are annualized.

Table 6: Correlation of Lev-factor with (un)conditional carry-factor

	Unconditional	Conditional
α	0.752	2.460**
	(1.019)	(1.325)
β	0.655**	0.444**
	(0.053)	(0.069)
R^2	0.332	0.119

Note: This table shows the regression cofficients of the conditional and the unconditional carry risk factors on the Lev-factor. Lev-factor is constructed from portfolios in Panel A of Table 5 while conditional and unconditional carry risk factors are constructed from portfolios in Panel B and C of Table 5, respectively. All numbers are annualized. ** indicates statistical significance at 5% level. * indicates statistically significance at 10% level.

Table 7: Estimation of the factor model: Lev-factor

	Panel A: Risk Factor Exposure					
	Lev-1	Lev-2	Lev-3	Fd-1	Fd-2	Fd-3
α	0.269	0.060	0.269	-0.036	-0.127	0.716
	(1.613)	(1.813)	(1.613)	(1.484)	(1.927)	(1.769)
β	-0.444**	0.056	0.556**	-0.228**	-0.046	0.427**
	(0.084)	(0.094)	(0.084)	(0.077)	(0.100)	(0.092)
R^2	0.084	0.001	0.125	0.028	0.001	0.066
Obs	312	312	312	312	312	312

Panel B: Price of Risk	
Fama-MacBeth	GMM
2.552**	2.134**
(0.342)	(0.925)

Note: Panel A in this table shows the exposure to the Lev-factor across the three currency portfolios sorted on unconditional average forward discount. Panel B reports the estimated price of the Lev-factor risk using the Fama-MacBeth and GMM methods. Hansen and Jagannathan (1997)'s scale-invariant weight matrix is used in the GMM estimation. Standard errors are Newey-West adjusted with 120 lags. All estimates of price of risk are annualized. ** indicates statistical significance at 5% level. * indicates statistically significance at 10% level.

Table 8: Procyclical Carry Trade Returns

	"AUD-JPY"	"NZD-CHF"	unconditional carry
α	-0.092	1.709	0.607
	(2.580)	(2.161)	(1.163)
β	0.300**	0.251**	0.155**
	(0.041)	(0.035)	(0.019)
R^2	0.121	0.121	0.148

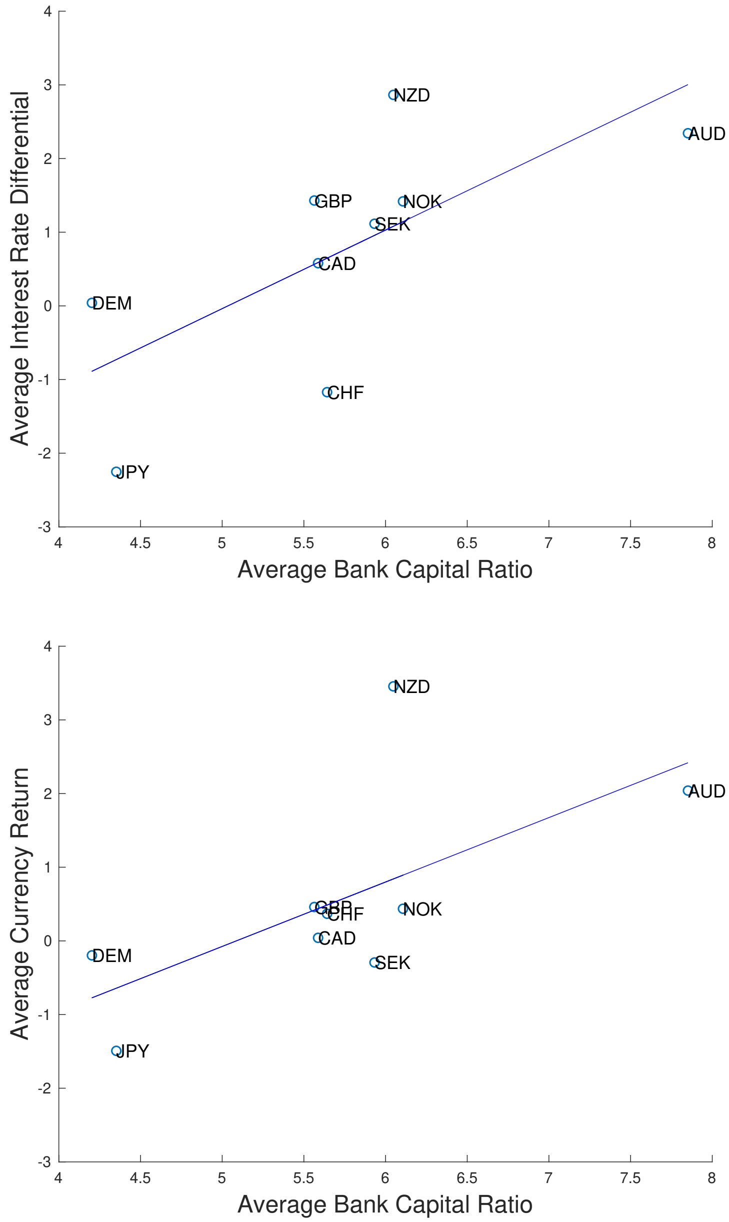
Note: This table shows the regression coefficients of three carry trade strategies' returns on the average bank stock return. The first column shows the result for the "AUD-JPY" strategy, the second column for the "NZD-CHF" strategy, and the third column for the unconditional carry strategy. All numbers are annualized. ** indicates statistically significance at 5% level. * indicates statistically significance at 10% level.

Table 9: Average Bank Stock Return as the Pricing Factor

Portfolio	(1)	(2)	(3)
Average return	0.780	0.927	2.877
Panel A: Risk Factor Exposure			
α	0.826	0.115	1.432
	(1.613)	(1.553)	(1.663)
β	-0.005	0.084**	0.150**
	(0.026)	(0.025)	(0.027)
R^2	0.000	0.028	0.074
Obs	398	398	398
Panel B: Price of Risk			
Fama-MacBeth		GMM	
12.852*		11.180*	
(7.840)		(6.673)	

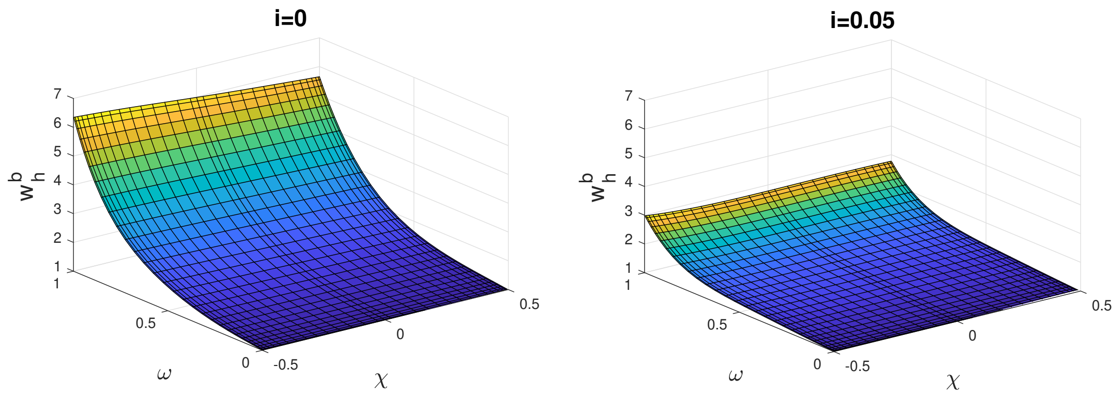
Note: The top row reports the average return to the three currency portfolios sorted on unconditional average forward discount. Panel A shows the exposures to the average bank stock return across the three currency portfolios. Panel B reports the estimated price of risk using the Fama-MacBeth and GMM methods. Hansen and Jagannathan (1997)'s scale-invariant weight matrix is used in the GMM estimation. Standard errors are Newey-West adjusted with 120 lags. All estimates of price of risk are annualized. ** indicates statistical significance at 5% level. * indicates statistically significance at 10% level.

Figure 1: Bank Capital Ratio, Interest Rate, and Currency Returns

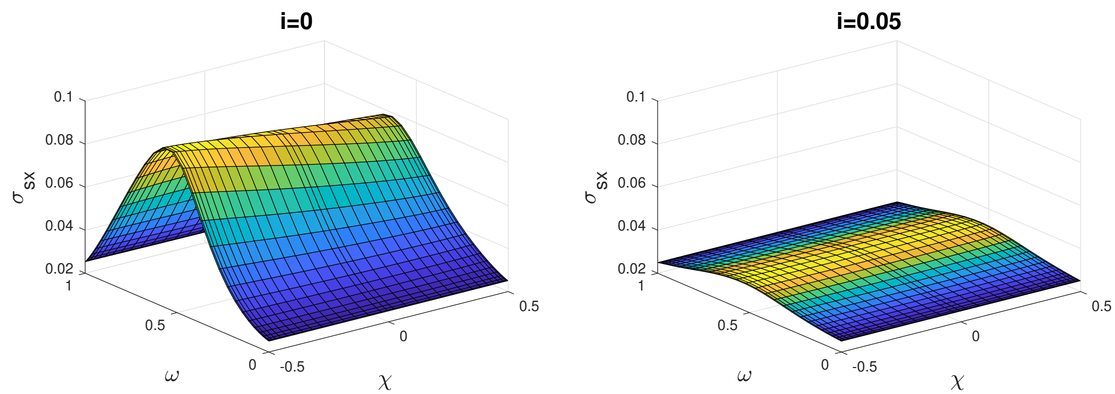


Note: Observations span from 1990 to 2016, with the currency data at monthly frequency and the bank balance sheet data at annual frequency. We select the the most liquid G10 countries with relatively long sample for comparability. We use German currency data before 1999 and Euro currency data after 1999.

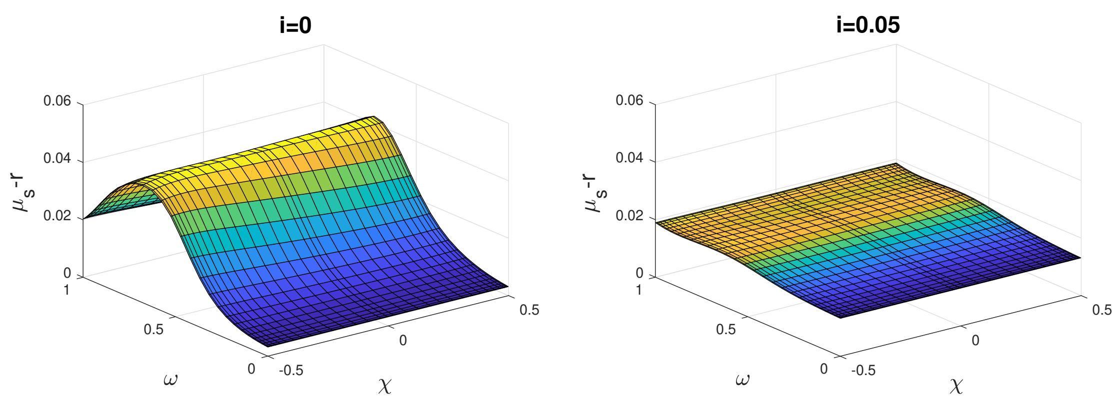
Figure 2: Leverage, Local Stock Return Exposure, and Excess Stock Return



Panel A: Bank Leverage



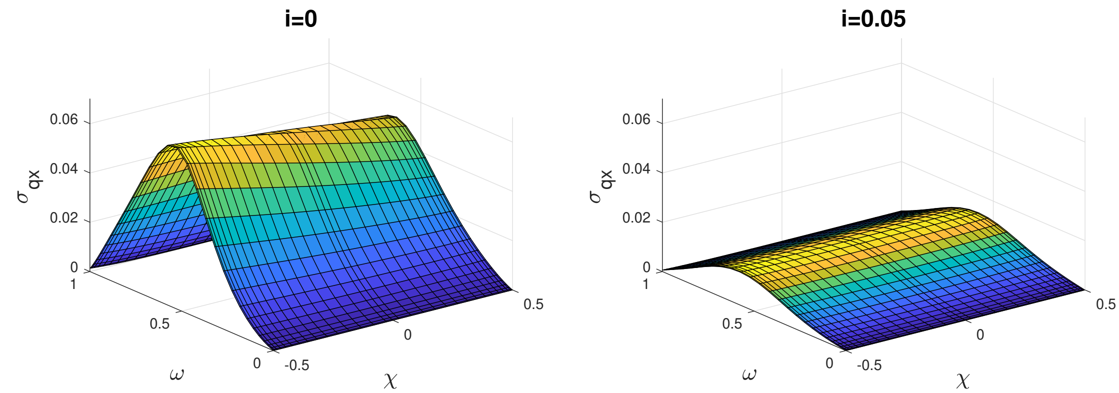
Panel B: Local Stock Return Exposure



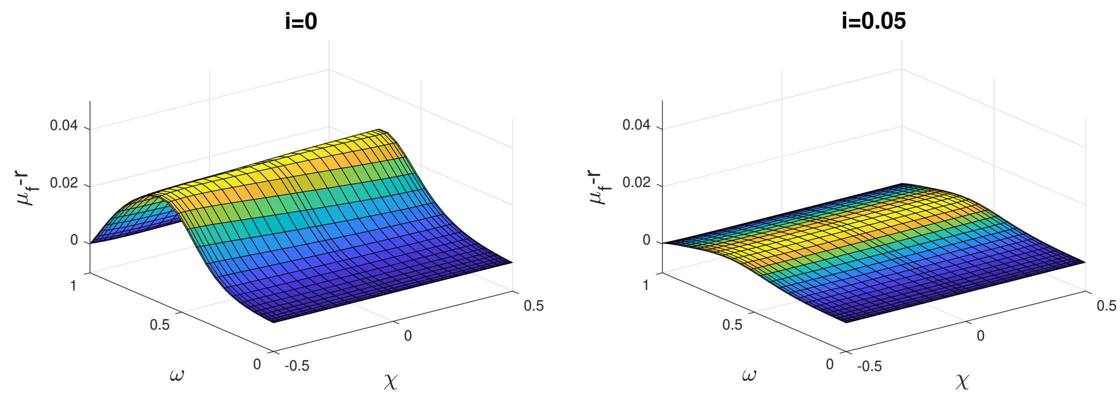
Panel C: Excess Local Stock Return

Note: This figure shows the solutions of bank leverage, excess local stock return, and local stock return exposure for economies with fixed nominal interest rate $i = 0$ and $i = 0.05$ in each panel, respectively. The graphs are on the same scale. ω represents the households' wealth share, and χ represents the scaled net foreign asset position.

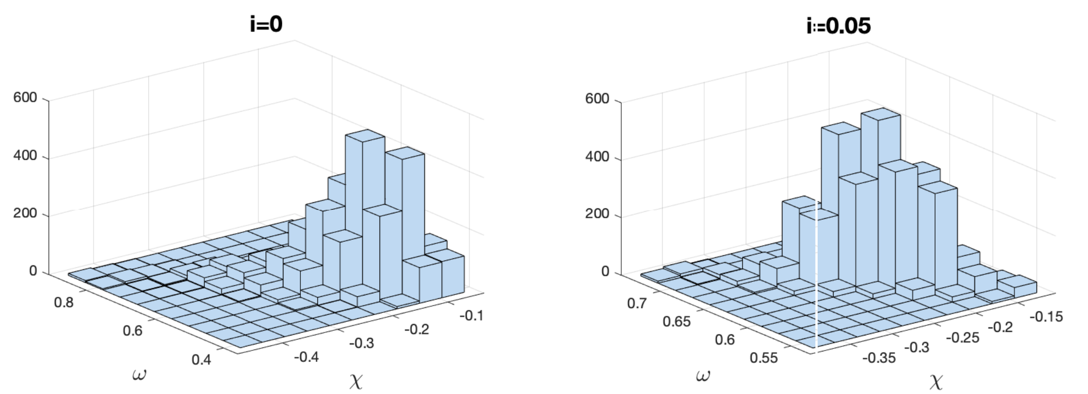
Figure 3: Exchange Rate Exposure, Currency Risk Premium, and Ergodic Distribution



Panel A: Exchange Rate Exposure



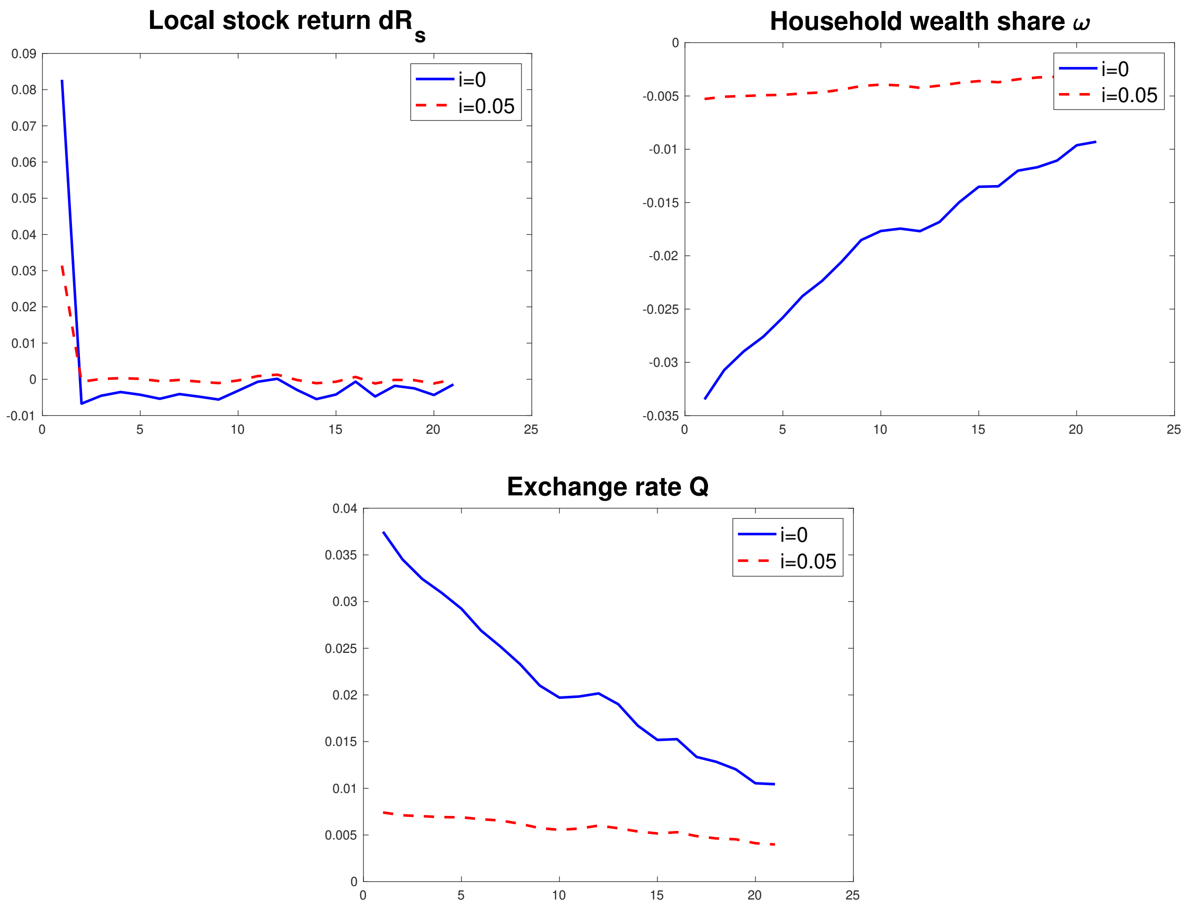
Panel B: Currency Risk Premium



Panel C: Ergodic Distribution

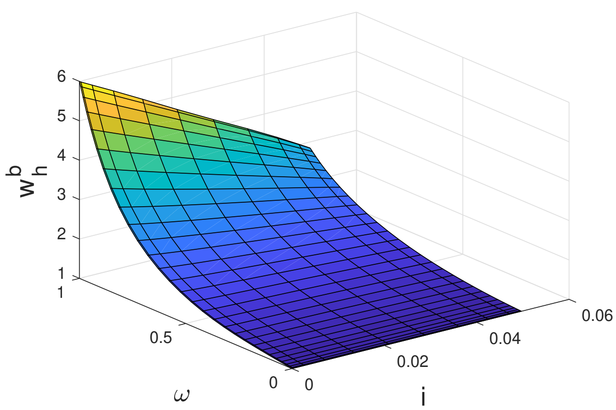
Note: This figure shows the solutions of exchange rate exposure and currency risk premium for economies with fixed nominal interest rate $i = 0$ and $i = 0.05$ in Panel A and B. Panel C shows the ergodic distribution of the two state variables. The graphs are on the same scale. ω represents the households' wealth share, and χ represents the scaled net foreign asset position.

Figure 4: Impulse Responses to a Positive Endowment Shock

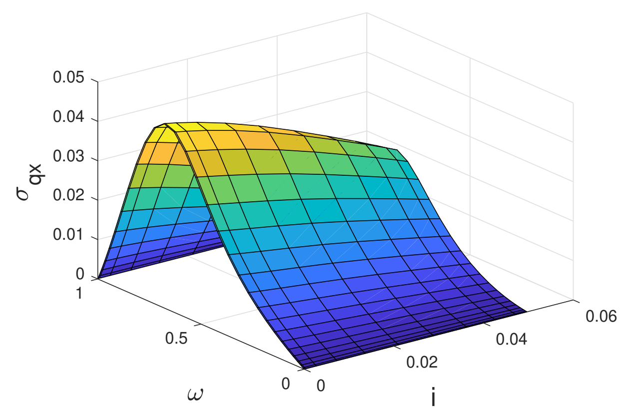


Note: This figure shows the impulse responses of various variables to a one standard deviation positive endowment shock in the two economies with $i = 0$ and $i = 0.05$. The solid blue line represents the $i = 0$ (low-interest-rate) economy and the dashed red line represents the $i = 0.05$ (high-interest-rate) economy. Impulse responses are obtained by simulation of $N = 2,000$ parallel economies and taking their average.

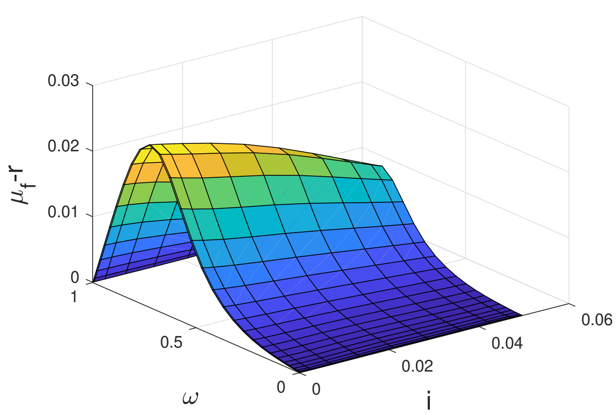
Figure 5: Solutions for the Stochastic Interest Rates



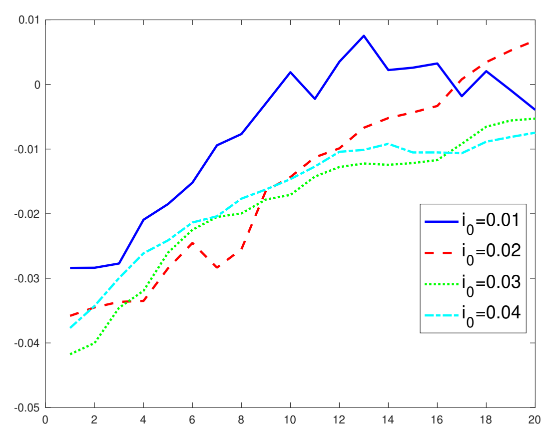
Panel A: Bank Leverage



Panel B: Exchange Rate Exposure



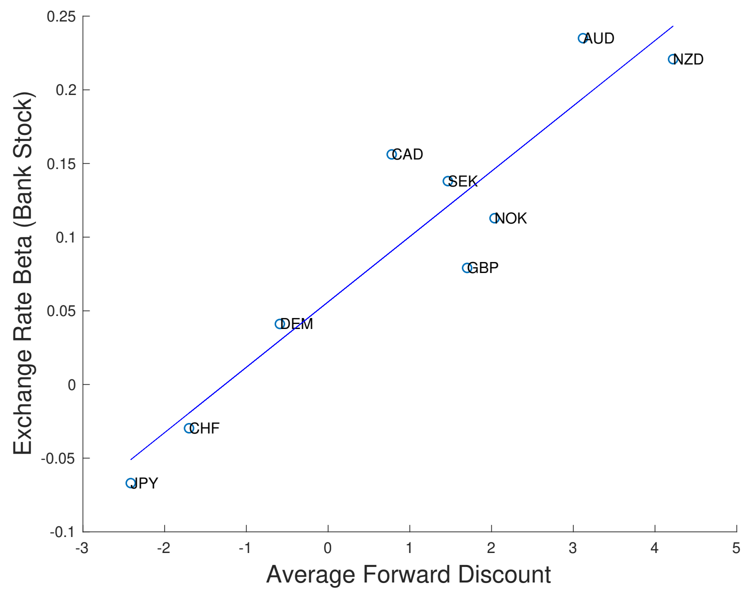
Panel C: Currency Risk Premium

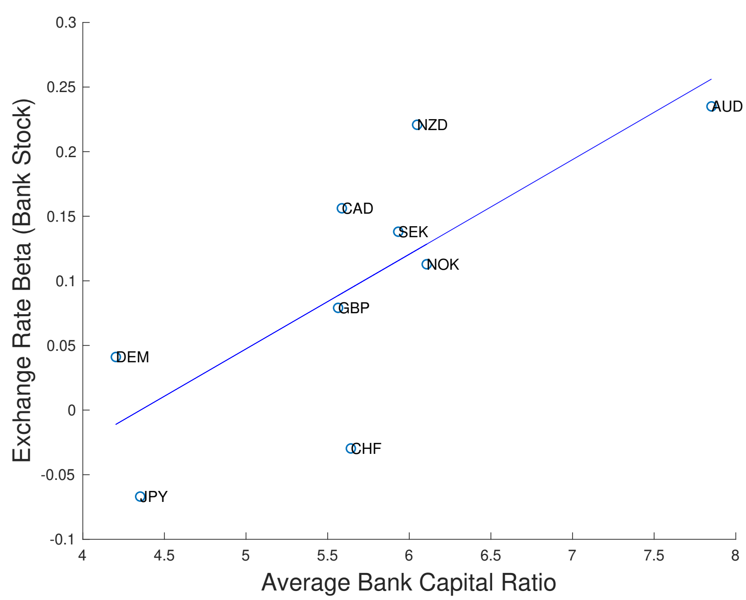


Panel D: Currency risk premium responses

Note: Panel A to C show the solutions of bank leverage w_h^b, exchange rate exposure σ_{qx}, and currency risk premium $\mu_f - r$ as functions of households' wealth share ω and nominal interest rate i, while fixing $\chi = 0$. Panel A to C are solutions to the economy with $i_0 = 0.01$. Panel D shows the impulse responses of currency risk premium (in percentage) to a positive nominal interest rate shock for the four economies. Impulse responses are obtained by simulation of $N = 1,000$ parallel economies and taking their average.

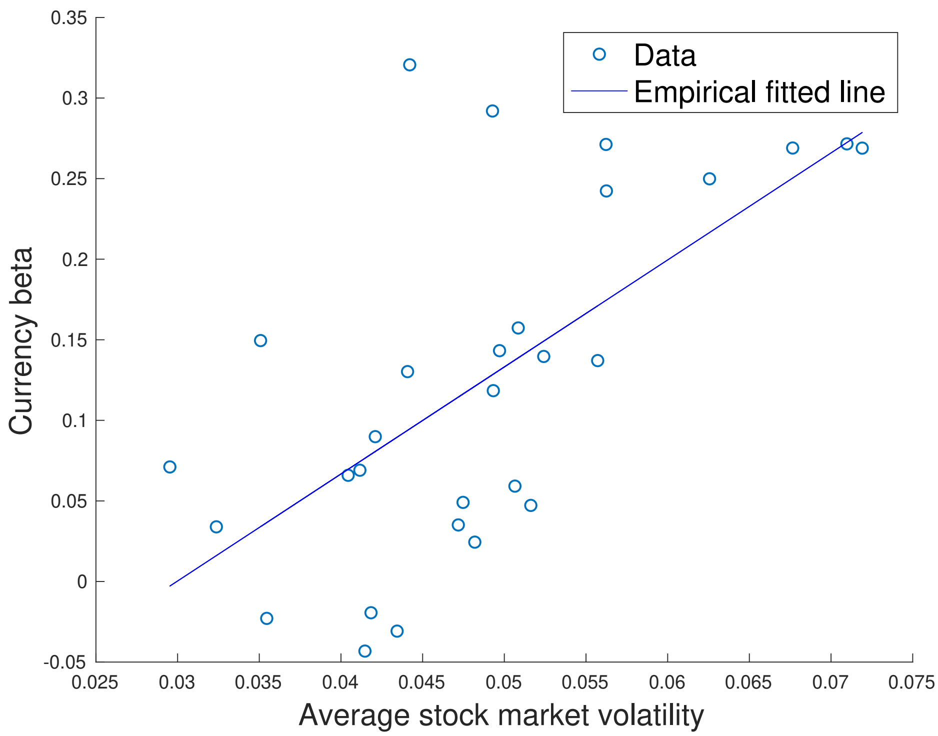
Figure 6: Currency Beta on Average Bank Stock Returns and Average Forward Discount





Note: This figure plots the relationship between a country's average forward discount (the upper panel) and average bank capital ratio (the lower panel) and the exchange rate beta with respect to the average bank stock return for the G10 currencies (vis-a-vis dollar). Data range from November 1983 to December 2016. Euro exchange rate is used for "DEM" after 1999.

Figure 7: Currency Beta and Stock Market Volatility



Note: This figure plots the relationship of time-varying currency beta of the carry trade portfolio to average stock return (using five-year rolling window) and the stock market volatility (monthly realized volatility of the average stock return across countries). Each dot represents an observation, and the solid blue line is the empirical fitted line.

Appendix A Proofs

A.1 Proof of Proposition 2

Using the definition in (12) and (13):

$$L_D^j - L_H^j = \frac{\lambda}{1+\lambda}\left[\max(w_h^j + w_c^j + w_f^j - 1, 0) + \max(-w_f^j, 0)\right]$$

$$-\frac{\lambda}{1+\lambda}\left[\max(1 - w_h^j - w_f^j - w_c^j, 0) + \max(w_f^j, 0)\right] - w_c^j \tag{54}$$

There are three cases in which the funding shock is relevant.

Case 1: $-w_h^j - w_c^j - w_f^j + 1 < 0, w_f^j < 0$. Under this case:

$$L_D^j - L_H^j = -w_c^j + \frac{\lambda}{1+\lambda}(w_h^j + w_c^j - 1) = -\frac{1}{1+\lambda}[w_c^j - \lambda(w_h^j - 1)$$

Case 2: $-w_h^j - w_c^j - w_f^j + 1 < 0, w_f^j > 0$. Under this case:

$$L_D^j - L_H^j = \frac{\lambda}{1+\lambda}(w_h^j + w_c^j + w_f^j - 1) - \frac{\lambda}{1+\lambda}w_f^j + w_c^j = -\frac{1}{1+\lambda}[w_c^j - \lambda(w_h^j - 1)]$$

Case 3: $-w_h^j - w_c^j - w_f^j + 1 > 0, w_f^j < 0$. Under this case:

$$L_D^j - L_H^j = -\frac{\lambda}{1+\lambda}w_f^j - \frac{\lambda}{1+\lambda}(1 - w_h^j - w_c^j - w_f^j) - w_c^j = -\frac{1}{1+\lambda}[w_c^j - \lambda(w_h^j - 1)]$$

We see that in three cases, the HJB equation shown in proposition 1 has the same form. Take the first order condition with w_c^j, we always have:

$$V_W^j W^j(-i) + V_{W+}^j \eta \frac{\phi}{1-\phi}\frac{1}{1+\lambda} > 0 \tag{55}$$

First, marginal utility of wealth decreases with W, so $V_W < V_{W+}$ for $W_+ > W$. Under Assumption 1, equation (55) always holds. Therefore, agent j chooses to hold enough liquid assets to protect herself from being exposed to the funding shock in all three cases, i.e.: $\max(L_D^j - L_H^j, 0) = 0$.

A.2 Proof of Proposition 3

There are four possible cases: $w_f^j > (<)0, w_f^j + w_h^j + w_c^j - 1 > (<)0$.

Case 1: $w_f^j < 0, w_f^j + w_h^j + w_c^j - 1 > 0$

$$L_D^j = \frac{\lambda}{1+\lambda}(w_h^j + w_c^j - 1), L_H^j = w_c^j$$

From $L_H^j \geq L_D^j$, we solve for:

$$w_c^j \geq \lambda(w_h^j - 1)$$

Case 2: $w_f^j > 0, w_f^j + w_h^j + w_c^j - 1 > 0$

$$L_D^j = \frac{\lambda}{1+\lambda}(w_h^j + w_c^j + w_f^j - 1), L_H^j = \frac{\lambda}{1+\lambda} w_f^j + w_c^j$$

From $L_H^j \geq L_D^j$, again we solve for:

$$w_c^j \geq \lambda(w_h^j - 1)$$

Case 3: $w_f^j < 0, w_f^j + w_h^j + w_c^j - 1 < 0$

$$L_D^j = -\frac{\lambda}{1+\lambda} w_f^j, L_H^j = w_c^j + \frac{\lambda}{1+\lambda}(1 - w_h^j - w_c^j - w_f^j)$$

From $L_H^j \geq L_D^j$, again we solve for:

$$w_c^j \geq \lambda(w_h^j - 1)$$

Case 4: $w_f^j > 0, w_f^j + w_h^j + w_c^j - 1 < 0$
Under this case, the agent does not borrow from either domestic agents or foreign agents, so optimal cash holding must be 0.

Combine the four cases together with $w_c^j \geq 0$, we can conclude that:

$$w_c^j = \max\{\lambda(w_h^j - 1), 0\} \tag{56}$$

A.3 Proof of Corollary 2

The proof starts from the equation (28) and (30). For simplicity, we only consider that for households. The same prodedure applies for bankers, except for that $\mu_s - r$ should be replaced by $\mu_s - r - \lambda i$.

As in the main text, we denote portfolio share as w, the diffusion of asset return as $\Sigma = \begin{bmatrix} \sigma_s & \sigma_f \end{bmatrix}$, and the diffusion of state variable Σ_Ω, with each column representing one state variables' exposure to various Brownian shocks.We supress j in the following proof. Equation (30) can be inverted into:

$$\mu - r = \gamma \Sigma' \Sigma w - \frac{1-\gamma}{1-\psi} \Sigma'_\Omega \Sigma (\frac{\nabla G}{G})' \tag{57}$$

$$= \gamma \frac{d}{dt} cov(dR, \frac{dW}{W}) - \frac{1-\gamma}{1-\psi} \frac{d}{dt} cov(dR, \frac{dG}{G}) \tag{58}$$

For given price of consumption basket $\tilde{P}$, we can write out the first order condition with respect to the consumption basket (though redundant given equations (26) and (27):

$$G = (\tilde{P}c)\tilde{P}^{\psi-1} \tag{59}$$

Therefore, equation (58) can be rewritten as:

$$\mu - r = -\frac{d}{dt}cov\left(\frac{1-\gamma}{1-\psi}\frac{d(\tilde{P}c)}{\tilde{P}c} - \gamma\frac{dW}{W} - (1-\gamma)\frac{d\tilde{P}}{\tilde{P}}, dR\right) \tag{60}$$

Appendix B Solution Details

In this section, we describe the details of how to solve the model numerically. We rely on Chebyshev approximations to the unknown functions. We start with a set of conjectured functions: value functions G^h, G^b, exchange rate Q, dividend yield of local stock F, and household portfolio share w_h^h, w_f^h. We only show the details for the case of fixed nominal interest rates, while extending the model to incorporate stochastic interest rate is straightforward with an additional state variable i.

The optimality conditions for consumption of traded and nontraded goods are shown in Corollary 1, equations (26) and (27). Combined with the CES aggregation equation (18), we can obtain:

$$c_x^j = G^j\alpha^\theta\left[\alpha^\theta + (1-\alpha)^\theta Q^{1-\theta}\right]^{\frac{\psi_j-\theta}{\theta-1}} \tag{61}$$

$$c_y^j = c_x^j\left(\frac{1-\alpha}{\alpha Q}\right)^\theta \tag{62}$$

The market clearing condition of nontraded good implies:

$$\omega c_x^h + (1-\omega)c_x^b = \frac{X}{W} \tag{63}$$

Define the dividend of local stock $Z = X + QY$, then:

$$\frac{dZ}{Z} = \left[\mu_x + \frac{Q\bar{\tau}}{1+Q\bar{\tau}}(\mu_q + \sigma_q'\sigma_x)\right]dt + \left[\sigma_x + \frac{Q\bar{\tau}}{1+Q\bar{\tau}}\left(\frac{Q_\omega}{Q}\sigma_\omega + \frac{Q_\chi}{Q}\sigma_\chi\right)\right]' d\mathbf{B} \equiv \mu_z dt + \sigma_z' d\mathbf{B} \tag{64}$$

As $F = \frac{Z}{P}$, the return process for local stock is:

$$dR_s = (F + \mu_P)dt + \sigma_P' d\mathbf{B} \tag{65}$$

where:

$$\sigma_P = \sigma_z - \frac{F_\omega}{F}\sigma_\omega - \frac{F_\chi}{F}\sigma_\chi \tag{66}$$

μ_P will be specified later. The volatilities of the state variables, from equations (40) and (42), are given by:

$$\sigma_\omega = (w_h^h - w_h^b)(\sigma_z - \frac{F_\omega}{F}\sigma_\omega - \frac{F_\chi}{F}\sigma_\chi) + (w_f^h - w_f^b)(\sigma^* + \frac{Q_\omega}{Q}\sigma_\omega + \frac{Q_\chi}{Q}\sigma_\chi) \tag{67}$$

$$\sigma_\chi = \chi\sigma^* \tag{68}$$

Thus, we can solve for σ_ω from equations (64), (67), and (68):

$$\sigma_\omega = \frac{(w_h^h - w_b^h)\left[\sigma_x + \frac{Q\bar{\tau}}{1+Q\bar{\tau}}\frac{Q_\chi}{Q}\chi\sigma^* - \frac{F_\chi}{F}\chi\sigma^*\right] + (w_f^b - w_f^b)(\sigma^* + \frac{Q_\chi}{Q}\chi\sigma^*)}{1 - (w_h^h - w_h^b)\left(\frac{Q\bar{\tau}}{1+Q\bar{\tau}}\frac{Q_\omega}{Q} - \frac{F_\omega}{F}\right) - (w_f^h - w_f^b)\frac{Q_\omega}{Q}} \tag{69}$$

Now that we can solve for all other volatilities, σ_q, σ_f, σ_z, and σ_P.

Next we derive the expected excess return of the two assets from the portfolio holding of households from Corollary 1:

$$\mu_s - r = \gamma_h\sigma_s'\sigma_s + \gamma_h\sigma_s'\sigma_f - \frac{1-\gamma_h}{1-\psi_h}\left(\frac{G_\omega^h}{G^h}\sigma_\omega'\sigma_s + \frac{G_\chi^h}{G^h}\sigma_\chi'\sigma_s\right) \tag{70}$$

$$\mu_f - r = \gamma_h\sigma_f'\sigma_f + \gamma_h\sigma_s'\sigma_f - \frac{1-\gamma_h}{1-\psi_h}\left(\frac{G_\omega^h}{G^h}\sigma_\omega'\sigma_f + \frac{G_\chi^h}{G^h}\sigma_\chi'\sigma_f\right) \tag{71}$$

According to market clearing condition, the portfolio holding of bankers are:

$$w_h^b = \frac{1 - \chi Q\frac{X}{W} - \omega w_h^h}{1-\omega}, w_f^b = \frac{\frac{X}{W}\chi Q - \omega w_f^h}{1-\omega} \tag{72}$$

where $\frac{X}{W}$ is given by equation (63).

Then we can derive the drift of state variables:

$$\mu_\omega = \omega(1-\omega)\left[c_x^h - c_x^b + Q(c_y^h - c_y^b) + (w_h^h - w_h^b)(\mu_s - r) + (w_f^h - w_f^b)(\mu_f - r) + w_c^b i + \Pi^h - \Pi^b\right] + \kappa(\bar{\omega} - \omega) \tag{73}$$

$$\mu_\chi = \tau - \left(\frac{1-\alpha}{\alpha Q}\right)^\theta + \chi r^* \tag{74}$$

Thus we can derive the drift of exchange rate μ_q, dividend μ_z, and the drift of local stock price change μ_P:

$$\mu_q = \frac{Q_\omega}{Q}\mu_\omega + \frac{Q_\chi}{Q}\mu_\chi + \frac{1}{2}\left(\frac{Q_{\omega\omega}}{Q}\sigma_\omega'\sigma_\omega + \frac{Q_{\chi\chi}}{Q}\sigma_\chi'\sigma_\chi\right) + \frac{Q_{\omega\chi}}{Q}\sigma_\omega'\sigma_\chi \tag{75}$$

$$\mu_z = \mu_x + \frac{Q\tau}{1+Q\tau}(\mu_q + \sigma_q'\sigma_x) \tag{76}$$

$$\mu_P = \mu_z + \sigma_P'\sigma_P - \sigma_z'\sigma_P - \mu_F \tag{77}$$

where:

$$\mu_F = \frac{F_\omega}{F}\mu_\omega + \frac{F_\chi}{F}\mu_\chi + \frac{1}{2}\left(\frac{F_{\omega\omega}}{F}\sigma_\omega'\sigma_\omega + \frac{F_{\chi\chi}}{F}\sigma_\chi'\sigma_\chi + 2\frac{F_{\omega\chi}}{F}\sigma_\omega'\sigma_\chi\right) \tag{78}$$

The expected return to local stock is $\mu_s = F + \mu_P$, and real risk free rate is $r = \mu_s - (\mu_s - r)$. Finally, we check whether the following conditions from (79) to (83) are satisfied.

The definition of dividend yield:

$$F = \frac{X(1+Q\bar{\tau})}{P} = \frac{X}{W}(1+Q\bar{\tau})\frac{1}{1-\chi Q\frac{X}{W}} \tag{79}$$

Consistency of foreign asset return:

$$\mu_f - r = r^* + \mu_q + \sigma_q'\sigma^* - r \tag{80}$$

Portfolio holding for bankers:

$$\mu_s - r - \lambda i = \gamma_b\sigma_s'\sigma_s + \gamma_b\sigma_s'\sigma_f - \frac{1-\gamma_b}{1-\psi_b}\left(\frac{G_\omega^b}{G^b}\sigma_\omega'\sigma_s + \frac{G_\chi^b}{G^b}\sigma_\chi'\sigma_s\right) \tag{81}$$

$$\mu_f - r = \gamma_b\sigma_f'\sigma_f + \gamma_b\sigma_s'\sigma_f - \frac{1-\gamma_b}{1-\psi_b}\left(\frac{G_\omega^b}{G^b}\sigma_\omega'\sigma_f + \frac{G_\chi^b}{G^b}\sigma_\chi'\sigma_f\right) \tag{82}$$

HJB equations for both agents:

$$\begin{aligned} 0 = {} & \frac{1}{1-\frac{1}{\psi_j}}\left[\frac{(c^j)^{1-\frac{1}{\psi_j}}}{(G^j)^{-\frac{1}{\psi_j}}} - (\rho+\kappa)\right] + \mu_w^j - \frac{1}{2}\gamma_j(\sigma_w^j)'\sigma_w^j + \frac{1}{1-\psi_j}\left(\frac{G_\omega^j}{G^j}\mu_\omega + \frac{G_\chi^j}{G^j}\mu_\chi\right) \\ & + \frac{1}{2(1-\psi_j)}\left[\frac{\psi_j-\gamma_j}{1-\psi_j}(\frac{G_\omega^j}{G^j} + \frac{G_{\omega\omega}^j}{G^j})\right]\sigma_\omega'\sigma_\omega + \frac{1}{2(1-\psi_j)}\left[\frac{\psi_j-\gamma_j}{1-\psi_j}(\frac{G_\chi^j}{G^j} + \frac{G_{\chi\chi}^j}{G^j})\right]\sigma_\chi'\sigma_\chi \\ & + \frac{1}{1-\psi_j}\left[\frac{\psi_j-\gamma_j}{1-\psi_j}\frac{G_\omega^j}{G^j}\frac{G_\chi^j}{G^j} + \frac{G_{\omega\chi}^j}{G^j}\right]\sigma_\omega'\sigma_\chi + \frac{1-\gamma_j}{1-\psi_j}\left[\frac{G_\omega^j}{G^j}\sigma_\omega + \frac{G_\chi^j}{G^j}\sigma_\chi\right]'\sigma_w^j \end{aligned} \tag{83}$$

where:

$$\mu_w^j = r - c_x^j - Qc_y^j + w_h^j(\mu_s - r) + w_f^j(\mu_f - r), \sigma_w^j = w_h^j\sigma_P + w_f^j\sigma_f \tag{84}$$

$$c^j = \left[\alpha(c_x^j)^{\frac{\theta-1}{\theta}} + (1-\alpha)(c_y^j)^{\frac{\theta-1}{\theta}}\right]^{\frac{\theta}{\theta-1}} \tag{85}$$

In total, we have six unknown functions and six equilibrium conditions to solve for them.

Appendix C Simulation Details

In our model, the low-interest-rate countries have higher bank leverage, so that bankers in these countries accumulate wealth faster than households and the ergodic distribution of ω will be highly tilted toward the bankers compared to those high-interest-rate countries. To make the ergodic mean of ω similar, we impose a wealth redistribution between bankers and households that keep the ergodic disribution of ω concentrating in the region of interest with a substantial currency risk premium. In the simulation, we specify Π^h and Π^b as:

$$\Pi^h = -\delta + \frac{\delta\bar{\omega}}{\omega}, \Pi^b = -\delta + \frac{\delta(1-\bar{\omega})}{1-\omega} + w_c^b i \tag{86}$$

In every period, δ fraction of each agent's wealth is taxed and redistributed. $\bar{\omega}$ fraction is redistributed to households and $1-\bar{\omega}$ is redistributed to bankers. We set δ to be larger in low interest rate countries, so that the ergodic mean of ω across countries are closer.

In our simulation in section 3.3, δ for each economy is set as 0.02, 0.014, 0.012, 0.008, 0.004, and 0, respectively.

We report the results without the introduction of the lump-sum redistribution in Appendix D.2, and find they do not affect the qualitative features of policy functions. The average carry trade return is smaller without the lump-sum redistribution.

The model is simulated using the solutions obtained in section 3.2. We use a two-point approximation of the standard Brownian motions: $dB = 1$ or -1 with equal probability $\frac{1}{2}$. We simulate 1000 periods for each economy and discard the first 100 periods for the computation of ergodic mean.

C.1 Impulse Response Functions

We solve the model globally and there is no deterministic steady state. To obtain the impulse response functions, we simulate $N = 2,000$ parallel economies. In each economy, we first simulate $T_1 = 120$ periods with randomly drawn Brownian shocks. For the period $T_1 + 1$, we set the domestic endowment shock to be 1 (a positive endowment shock) for all economies. Then each economy evolves freely for $T_2 = 20$ periods. We take the average of each variable across the 2,000 parallel economies for T_2 periods, and subtract their average values in period T_1, the ergodic mean.

Appendix D Additional Results with the Model

D.1 Current Account Cyclicality

In this section, we look at the impulse response of current account surplus (in terms of the traded good) scaled by X in the model with fixed interest rates, as in section 3.2. In our model, the current account surplus is equal to $\overline{CA} = Y - C_y^h - C_y^b$. It is a monotonic function of exchange rate Q:

$$CA = \frac{\overline{CA}}{X} = \bar{\tau} - (\frac{1-\alpha}{\alpha Q})^{\theta} \tag{87}$$

Therefore, the impulse responses of CA mirrors the responses of Q. The current account surplus increases when there is a positive endowment shock to the economy.

In the international business cycle literature, it has been widely known that current account is countercyclical, while our model predicts a procyclical current account surplus. The driving force of current account countercyclicality is investment, which is abstracted away from our model. If we redefine output as the sum of nondurable good and service consumption plus net export, the correlation between net export and output is positive for most advanced economies. The correlation between consumption, net export, and the sum of the two (defined as output) are shown in Table E.1[15].

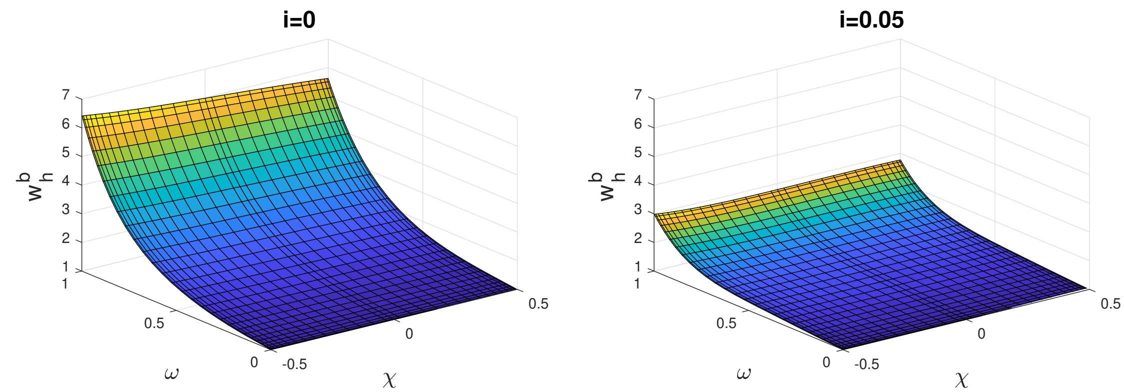
D.2 Fixed Interest Rates without Redistribution

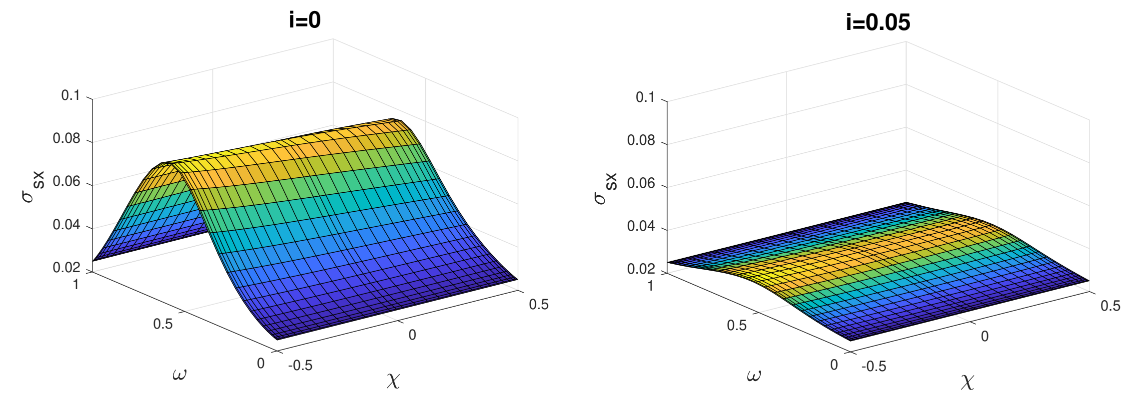
In this appendix, we repeat the numerical solution to the model with $\Pi^h = 0, \Pi^b = w_c^b i$. The purpose is to show that the change in redistribution does not change the policy functions or impulse responses, while making the currency return spread between $i = 0$ and $i = 0.05$ economy smaller. All qualitative results remain.

We show the counterpart of Figure 2 and Figure 3 in Figure D.1 and Figure D.2, the counterpart of Figure 4 in Figure D.3, and the counterpart of Table 2 in Table D.1.

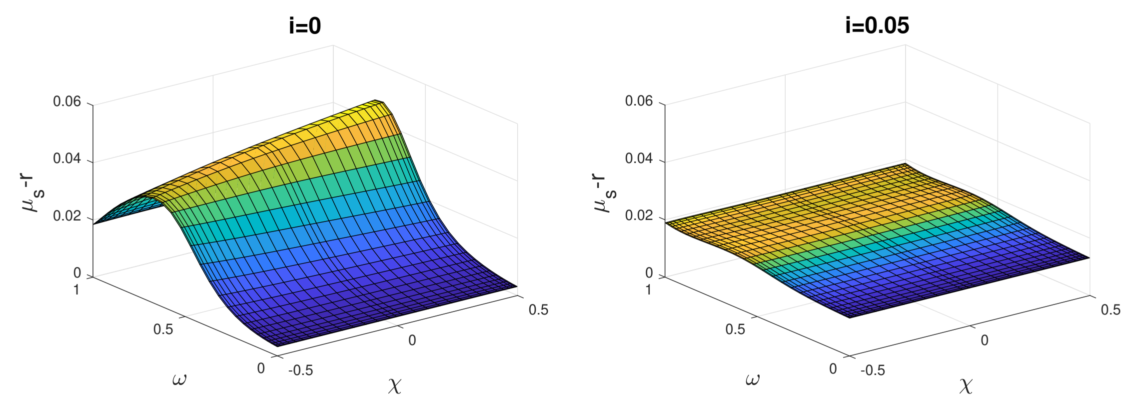
[15] I thank Yang Liu for sharing the data.

Figure D.1: Leverage, Local Stock Return Exposure, and Excess Stock Return





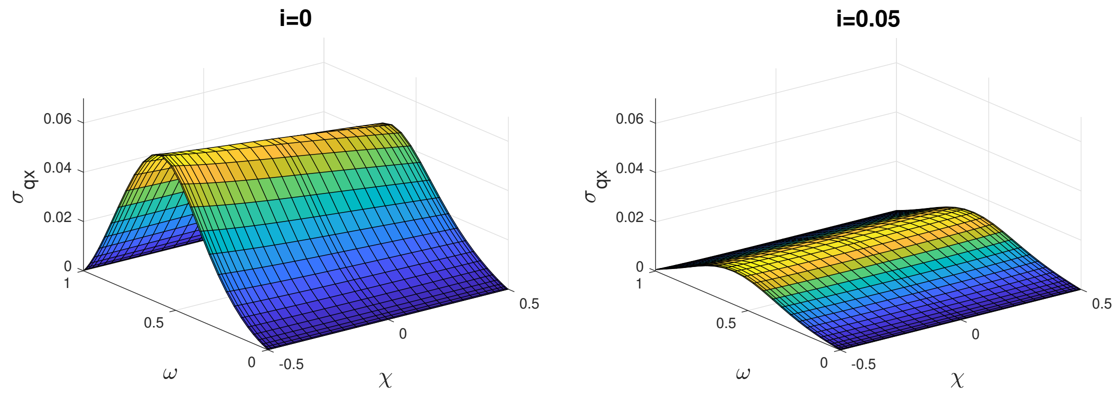
Panel B: Local Stock Return Exposure



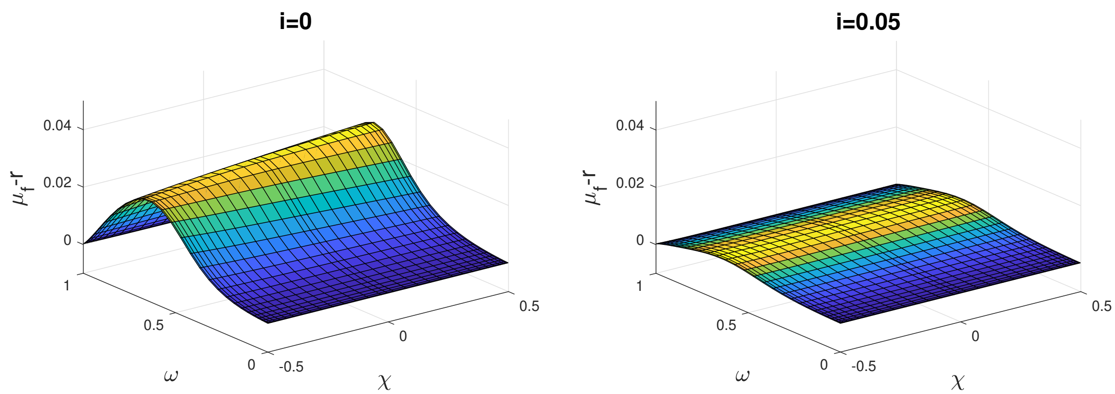
Panel C: Excess Local Stock Return

Note: This figure shows the solutions of bank leverage, excess local stock return, and local stock return exposure for economies with fixed nominal interest rate $i = 0$ and $i = 0.05$ in each panel, respectively. The graphs are on the same scale. ω represents the households' wealth share, and χ represents the scaled net foreign asset position.

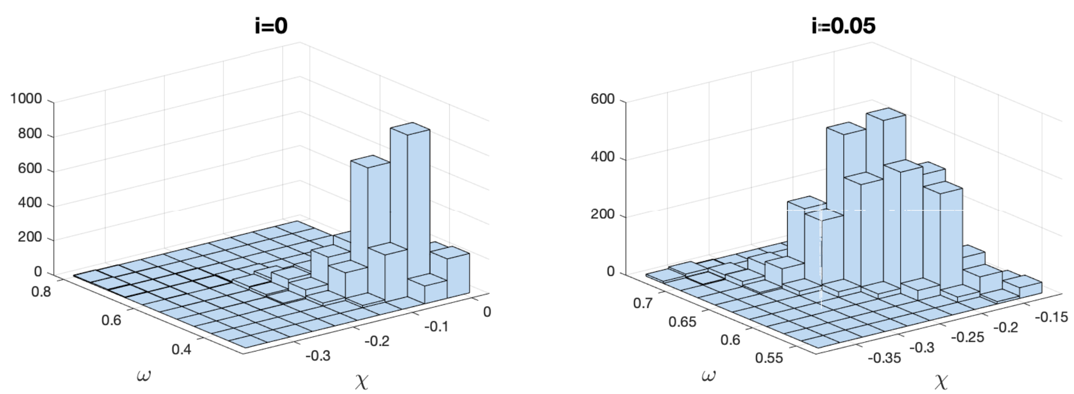
Figure D.2: Exchange Rate Exposure and Currency Risk Premium



Panel A: Exchange Rate Exposure



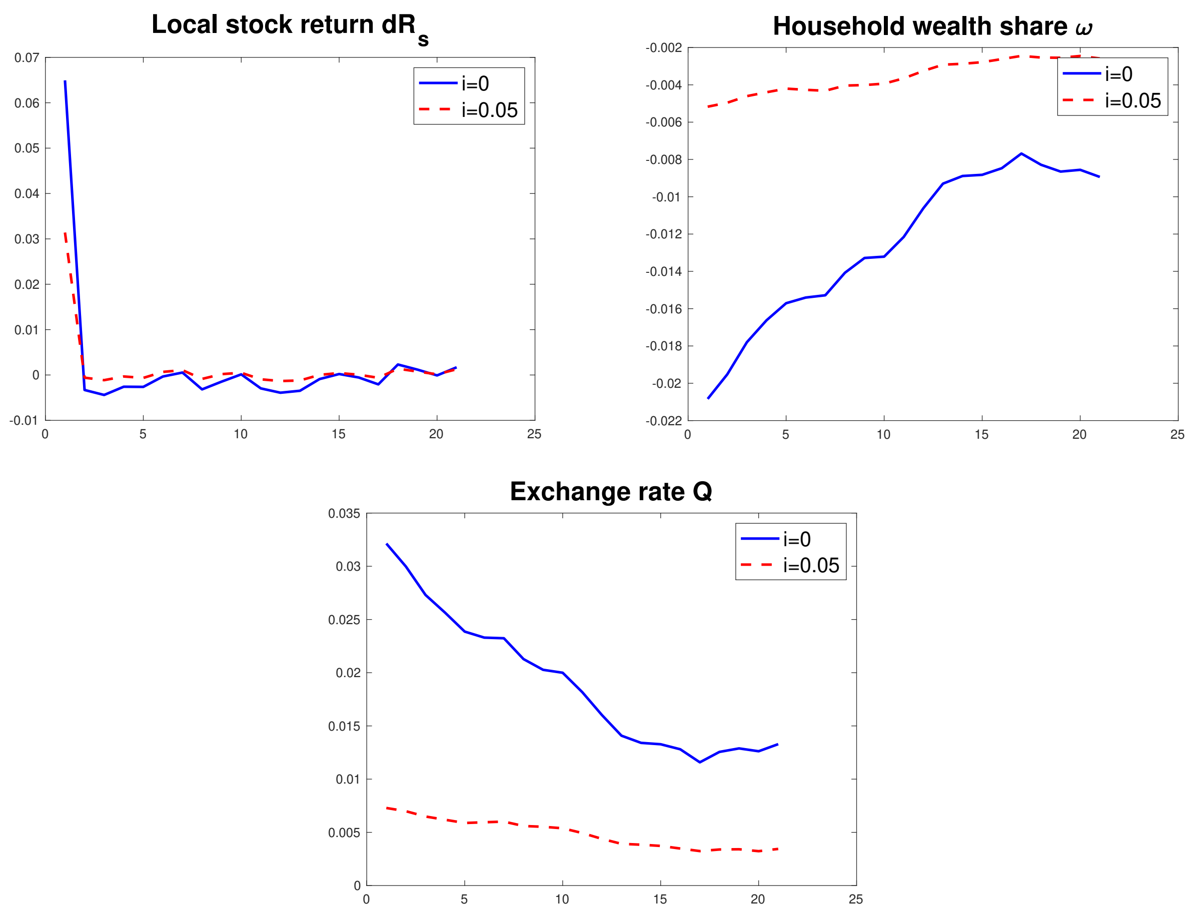
Panel B: Currency Risk Premium



Panel C: Ergodic Distribution

Note: This figure shows the solutions of exchange rate exposure and currency risk premium for economies with fixed nominal interest rate $i = 0$ and $i = 0.05$ in Panel A and B. Panel C shows the ergodic distribution of the two state variables. The graphs are on the same scale. ω represents the households' wealth share, and χ represents the scaled net foreign asset position.

Figure D.3: Impulse Responses to a Positive Endowment Shock



Note: This figure shows the impulse responses of various variables to a one standard deviation positive endowment shock in the two economies with $i = 0$ and $i = 0.05$. The solid blue line represents the $i = 0$ (low-interest-rate) economy and the dashed red line represents the $i = 0.05$ (high-interest-rate) economy. Impulse responses are obtained by simulation of $N = 2,000$ parallel economies and taking their average.

Table D.1: Simulation Results for A Cross-Section of Economies with Fixed Interest Rates

i	0	0.01	0.02	0.03	0.04	0.05
Panel A: Asset Prices (in percent)						
μ_s	3.538	3.617	3.675	3.766	3.986	4.183
r	1.695	2.023	2.201	2.327	2.134	2.392
$\mu_s - r$	1.843	1.594	1.474	1.438	1.852	1.791
σ_{sx}	6.327	5.274	4.634	4.105	3.674	3.161
σ_{qx}	3.782	2.891	2.496	2.222	1.897	1.225
$\mu_f - r$	1.109	0.789	0.620	0.502	0.708	0.457
Panel B: Portfolio Choices						
w_h^b	1.557	1.527	1.484	1.421	1.385	1.367
w_f^b	-0.008	0.050	0.101	0.144	0.197	0.228
w_h^h	0.272	0.388	0.491	0.581	0.667	0.785
w_f^h	0.007	-0.060	-0.108	-0.146	-0.174	-0.139
Panel C: State Variables						
ω	0.425	0.457	0.483	0.498	0.534	0.626
χ	-0.073	-0.084	-0.111	-0.120	-0.161	-0.221
Panel D: Return Exposures						
β_{FX}	1.178	0.809	0.645	0.529	0.390	0.178
β_s	1.400	1.166	1.024	0.906	0.810	0.695
$\beta_{FX,s}$	0.865	0.666	0.581	0.522	0.452	0.302
$\beta_{FX,b}$	0.581	0.445	0.386	0.346	0.299	0.199

Appendix E Additional Empirical Results

E.1 Consumption, Net Export, and Output

Table E.1 shows the correlation between growth rates of nondurable good and service consumption (c), net export nx, and the sum of the two, y.

Table E.1: Correlation of Consumption, Net Export, and Output

	$corr(c, y)$	$corr(c, nx)$	$corr(nx, y)$
US	0.95	-0.29	0.26
Canada	0.43	-0.24	0.77
France	0.68	-0.18	0.59
Germany	0.63	-0.15	0.67
Italy	0.51	-0.31	0.66
Japan	0.84	0.00	0.54
UK	0.74	-0.08	0.61
Australia	0.42	-0.23	0.79
Belgium	0.10	-0.24	0.94
Denmark	0.72	-0.12	0.61
Netherlands	0.56	-0.10	0.77
New Zealand	0.56	-0.13	0.75
Norway	0.11	-0.27	0.92
Potugal	0.29	-0.41	0.76
Spain	0.36	-0.74	0.36
Sweden	0.49	-0.11	0.81
Switzerland	0.38	-0.09	0.89
G7	0.67	-0.18	0.59
G10	0.40	-0.24	0.76
Mean	0.51	-0.22	0.69

Note: This table shows the correlations of consumption, output, and net export growth rate for 17 countries, as well as the average of the correlations for G7, G10, and G17. Consumption only consists of nondurable goods and services, and output is equal to the consumption of nondurable goods and services plus net exports. Data span 1970 to 2014 at quarterly frequency.

E.2 Panel Regressions with Emerging Economies

Table E.2 in this subsection shows the results analogous to Table 4 with 44 countries including emerging economies of Bulgaria, Chile, Czech Republic, Egypt, Hong Kong, Hungary, India, Indonesia, Israel, Malaysia, Mexico, Philippines, Poland, Russia, Saudi Arabia, Singapore, Slovakia, South Africa, Taiwan, Thailand, Turkey, and Ukraine.

Table E.2: Bank capital ratio, forward discount, and currency return with emerging economies

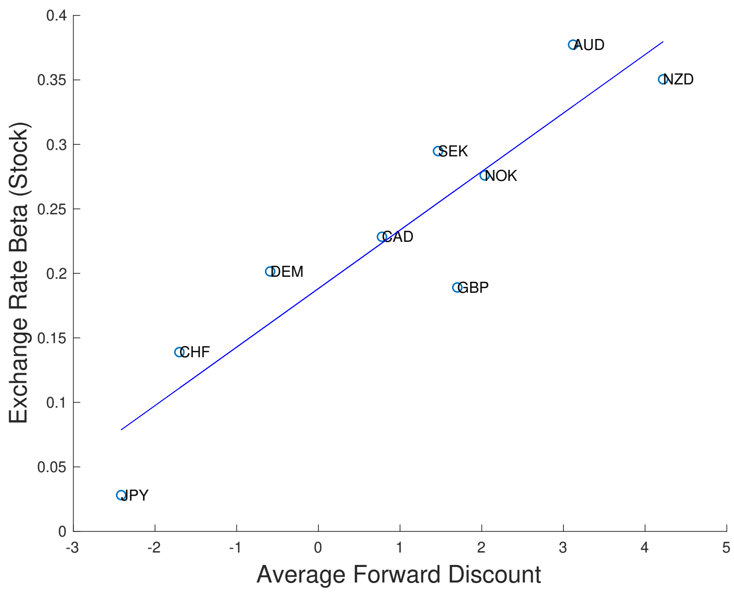
	Forward discount				Currency return			
	(1)	(2)	(3)	(4)	(1)	(2)	(3)	(4)
Capital ratio	0.385**	0.330**	0.289**	0.267**	0.419**	0.019	0.455**	-0.038
	(0.033)	(0.057)	(0.074)	(0.047)	(0.128)	(0.034)	(0.052)	(0.061)
Inflation		0.534**		0.541**		0.178		0.114
		(0.065)		(0.031)		(0.481)		(0.501)
GDP			-0.388*	-0.323**			-0.466**	-0.210
			(0.235)	(0.032)			(0.057)	(0.469)
R^2	0.079	0.428	0.099	0.446	0.064	0.167	0.096	0.198

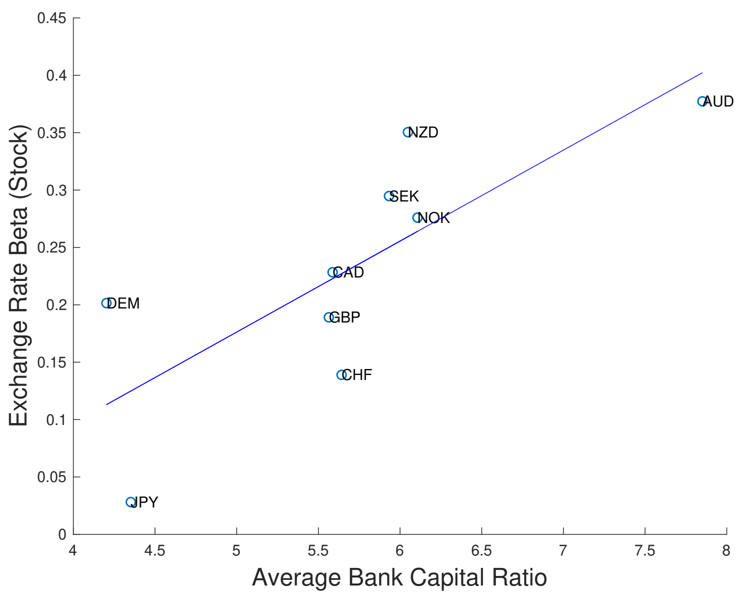
Note: Fama-Macbeth regression results of the forward discount (left panel) and the currency return (right panel) on the bank capital ratio (the inverse of leverage, in percentage). In both panels, column (1) report the univariate regression coefficients. Column (2) controls for inflation, column (3) controls for the log GDP (size) of each country, and column (4) controls for both inflation and log GDP. Data are monthly including 44 countries, from Jan 1990 to Dec 2016. Both advanced economies and emerging economies are included. Annual measures of the bank capital ratio and the GDP share are used repetitively for months within a year. Standard errors are Newey-West adjusted with 120 lags. ** indicates statistical significance at 5% level. * indicates statistical significance at 10% level.

E.3 Average Stock Return as a Risk Factor

Figure E.1 and Table E.3 in this section show results analogous to Figure 6 and Table 9, while replacing the average bank stock return with average country MSCI indices in the cross-section. The results are similar with using the average bank stock return.

Figure E.1: Currency Beta on Global Stock Returns and Average Forward Discount





Note: This figure plots the relationship between a country's average forward discount (the upper panel) and the average bank capital ratio (the lower panel) and the exchange rate beta with respect to the average stock return for the G10 currencies (vis-a-vis dollar). Data range from November 1983 to December 2016. Euro exchange rate is used for "DEM" after 1999.

Table E.3: Average Stock Return as the Pricing Factor

Portfolio	(1)	(2)	(3)
Average return	0.780	0.927	2.877
Panel A: Risk Factor Exposure			
α	-1.014	-1.570	-0.391
	(1.521)	(1.383)	(1.418)
β	0.184**	0.257**	0.336**
	(0.026)	(0.024)	(0.024)
R^2	0.114	0.231	0.329
Obs	398	398	398

Panel B: Price of Risk	
Fama-MacBeth	GMM
14.019**	8.018
(6.499)	(5.053)

Note: The top row reports the average return to the three currency portfolios sorted on the unconditional average forward discount. Panel A shows the exposures to average stock returns across the three currency portfolios. Panel B reports the estimated price of risk using the Fama-MacBeth and GMM methods. Hansen and Jagannathan (1997)'s scale-invariant weight matrix is used in the GMM estimation. Standard errors are Newey-West adjusted with 120 lags. All estimates of price of risk are annualized. ** indicates statistical significance at 5% level. * indicates statistically significance at 10% level.