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EXCHANGE RATES AND ASSET PRICES IN A GLOBAL DEMAND SYSTEM

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ABSTRACT

We develop an asset demand system to study exchange rates, short-term rates, long-term yields, and equity prices across 37 countries. Using international portfolio holdings data, we estimate the asset demand system by instrumental variables. We develop a unified framework to decompose the variation in exchange rates and asset prices into portfolio flows and shifts in asset demand, to interpret economic events such as the European sovereign debt crisis, and to estimate the convenience yield on US assets. The convenience yield is 1.45 percent on the US dollar, 2.81 percent on long-term debt, and 0.50 percent on equity.

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We develop an asset demand system to study exchange rates, short-term rates, long-term yields, and equity prices across 37 countries from 2003 to 2020. The demand system approach starts with the observation that every asset pricing model is a model of asset demand, which arises from optimal portfolio choice, and market clearing. We derive the asset demand system from a traditional model of consumption and portfolio choice under heterogeneous beliefs, which imply heterogeneous portfolios in equilibrium. For each investor country, optimal consumption implies an Euler equation for its short-term rate, and optimal portfolio choice implies portfolio weights across the three asset classes and 37 issuer countries. By market clearing, the supply of each asset must equal the aggregate demand across all investor countries. Accounting for the euro area and two currency pegs, the asset demand system determines 25 exchange rates relative to the US dollar, 26 short-term rates, 37 long-term yields, and 37 equity prices.

We match international portfolio holdings together with exchange rates and asset prices across all countries, taking the portfolio choice implications of international asset pricing models to their logical conclusion. We develop a nested logit model with substitution across countries in the inner nest and across asset classes in the outer nest. The nested logit model nests the traditional mean-variance portfolio and the logit model of asset demand (Koijen and Yogo 2019) as special cases but allows for more flexible substitution effects, suited for our application. Within each asset class, the allocation across countries depends on asset prices (equivalently, yields in the case of debt), real exchange rates, and macro variables such as gross domestic product (GDP), GDP per capita, inflation, equity volatility, and the sovereign debt rating. Asset demand also depends on the bilateral distance between investor and issuer countries to capture gravity (Portes et al. 2001; Portes and Rey 2005) and an indicator variable for domestic ownership to capture home bias. Asset demand also depends on latent demand, which are characteristics unobserved by the econometrician, to match the data on international portfolio holdings.

We estimate the asset demand system on international portfolio holdings data (International Monetary Fund 2003–2020a; U.S. Department of the Treasury 2003–2020). The International Monetary Fund aggregates foreign exchange reserves across all foreign central banks for confidentiality, which we treat as a separate investor unit. To account for investments through tax havens, we restate the international portfolio holdings from residency to nationality accounting, based on the Global Capital Allocation Project (Coppola et al. 2021). We also use the available information on the currency composition to separate local and foreign currency assets. We aggregate assets outside of the 37 countries and foreign currency assets into an outside asset for each asset class.

We estimate the asset demand system by instrumental variables because exchange rates and asset prices are endogenous with latent demand. By market clearing, an investor's asset demand equals the residual supply, which is supply minus the sum of asset demand across all other investors. Thus, identification requires exogenous variation in the residual supply. We isolate cross-sectional variation in the residual supply, based on the relative size of countries and the bilateral distance between them. We estimate a gravity equation to predict asset demand and a cross-sectional regression of asset quantities on GDP and population to predict supply. We then construct the predicted residual supply as the predicted supply minus the sum of predicted demand across all other investors. We explain the intuition for the identification strategy through an example. In the long-term debt market, the Netherlands and Australia have similar values for the predicted supply because they are similar in size as measured by a weighted average of GDP and population. However, the predicted demand is much higher for Dutch long-term debt than for Australian long-term debt. The gravity effect favors the Netherlands over Australia because it neighbors large investor countries in Europe. Thus, US investors face lower expected returns on Dutch long-term debt, through a higher long-term debt price and/or a higher real exchange rate. Generalizing this example, smaller issuer countries that are in close proximity to larger investor countries have a higher exogenous component of asset demand and consequently higher asset prices and/or real exchange rates.

An important aspect of the demand system approach is that we treat the demand elasticities as free parameters, instead of imposing theoretically implied elasticities that are rigid moments of returns. Traditional models, such as the capital asset pricing model, imply demand elasticities that are several orders of magnitude greater than the empirical estimates (Petajisto 2009). We estimate mean demand elasticities of 25.2 (1.9) for short-term debt, 3.1 (0.4) for long-term debt, and 1.2 (1.0) for equity with the standard errors in parentheses. That is, the aggregate demand for a country's equity decreases by 1.6 percent per one percent increase in its price. Accounting for differences in the level of aggregation, identification strategies, and sampling error, our demand elasticities are broadly consistent with the estimates for euro-area government debt (Koijen et al. 2021), US corporate bonds (Bretscher et al. 2023; Chaudhary et al. 2023), and US stocks (Chang et al. 2014; Koijen and Yogo 2019; Pavlova and Sikorskaya 2022). These papers use more granular portfolio holdings data on institutions and households but focus on a narrower set of countries and asset classes, ruling out potentially important substitution effects. We use portfolio holdings at the country level but allow for the full range of substitution effects across countries and asset classes.

Based on the estimated demand system and market clearing, we develop a variance decomposition of exchange rates and asset prices. We decompose the annual variation in exchange rates and asset prices into portfolio flows and shifts in asset demand through macro variables and latent demand. The macro variables explain 16 percent of the variation in exchange rates. Latent demand explains 57 percent of the variation in exchange rates, of which foreign exchange reserves explain 10 percent. The macro variables explain 14 percent, and latent demand explains 86 percent of the variation in short-term rates. Portfolio flows explain 58 percent, and the macro variables explain 41 percent of the variation in long-term yields. Portfolio flows explain 20 percent, and the macro variables explain 19 percent of the variation in log market-to-book equity. Latent demand explains 56 percent of the variation in market-to-book equity, of which North American investors explain 15 percent and European investors explain 26 percent.

By focusing on particular countries and asset classes, we can use the same variance decomposition to interpret major economic events. We illustrate this application through the European sovereign debt crisis, focusing on the extreme long-term yield movements in Greece, Italy, and Portugal. In Greece, the macro variables are relatively more important than latent demand. The macro variables explain 47 percent, and latent demand explains 31 percent of the variation in the Greek long-term yield. In Italy and Portugal, latent demand is relatively more important than the macro variables. Latent demand explains all of the variation in the Italian long-term yield and 73 percent of the variation in the Portuguese long-term yield. European investors alone explain 96 percent of the variation in the Italian long-term yield and 64 percent of the variation in the Portuguese long-term yield. These results confirm the narrative that Greece was insolvent, while Italy and Portugal were still solvent but perceived to be vulnerable.

US assets enjoy a special status because the US dollar is the global reserve currency and US Treasury debt is the global safe asset (Gourinchas and Rey 2007; Jiang et al. 2021). Consistent with this view, the cross-sectional mean of the foreign investors' latent demand for US assets is consistently high across years and asset classes. We compute the counterfactual asset prices in the absence of special demand for US assets, by subtracting the cross-sectional mean from the foreign investors' latent demand for US assets. In the absence of special status, a value-weighted exchange rate of US dollars per local currency unit is 5.36 percent higher. Consequently, the expected annual return on a value-weighted portfolio of foreign short-term debt is 1.45 percent lower. The US long-term yield is 0.76 percent higher, and its expected annual return is 2.81 percent higher. The US market-to-book equity is 3.37 percent lower, and its expected annual return is 0.50 percent higher. Thus, in units of expected annual returns, the mean convenience yield is 1.45 percent on the US dollar, 2.81 percent on US long-term debt, and 0.50 percent on US equity.

Motivated by the arbitrage pricing theory or the intertemporal capital asset pricing model, an empirical literature tests for a low-dimensional factor structure in global stock

(Fama and French 2012), bond (Dahlquist and Hasseltoft 2013; Jotikasthira et al. 2015), and currency returns (Lustig et al. 2011). These papers find both common and local factors across countries within each asset class. Asness et al. (2013) find common factors in value and momentum returns across countries and asset classes. Like this literature, we develop an asset pricing model that sheds light on the sources of variation in global stock, bond, and currency returns. We take a further step of explaining international portfolio holdings together with exchange rates and asset prices, connecting the variation in returns to the global investors who hold these assets.

The remainder of the paper is organized as follows. In Section I, we develop an endowment economy with two periods, two countries, and two assets to illustrate how an asset demand system determines exchange rates and asset prices. In Section II, we extend the asset demand system to multiple countries and three asset classes, designed to match international portfolio holdings. In Section III, we describe the data on international portfolio holdings, asset prices, and asset characteristics. In Section IV, we estimate the asset demand system by instrumental variables. In Section V, we present a variance decomposition of exchange rates and asset prices, based on the estimated demand system and market clearing. We also present a case study of the European sovereign debt crisis. In Section VI, we estimate the convenience yield on US assets. Section VII concludes.

I. Two-Country Model of Exchange Rates and Asset Prices

We develop an endowment economy with two periods, two countries, and two assets that leads to Euler equations for optimal consumption and portfolio choice. We then derive an asset demand system that determines exchange rates and asset prices through market clearing for consumption goods and the two assets. We denote the two periods as t and $t+1$. The two countries are the United States and Japan with a representative investor in each country. To obtain heterogeneous portfolios in equilibrium, we assume that US and Japanese investors have heterogeneous beliefs and agree to disagree.

A. Asset Markets

We denote the US consumer price index as $B_{U,t}$ dollars and the Japanese consumer price index as $B_{J,t}$ yen at time t. Then $V_t = B_{U,t}/B_{J,t}$ is the relative price index in dollars per yen at time t. Let E_t be the nominal exchange rate in dollars per yen at time t. Then E_t/V_t is the real exchange rate.

There is a riskless nominal bond in each country. The US bond has price $P_t(U)$ dollars at time t and payoff \$1 at time $t+1$. We denote its gross return in dollars as $R_{t+1}(U) = 1/P_t(U)$. The predetermined face value of US bonds outstanding is $Q_t(U)$ dollars. The Japanese bond has price $P_t(J)$ yen at time t and payoff ¥1 at time $t+1$. We denote its gross return in yen as $R_{t+1}(J) = 1/P_t(J)$. The predetermined face value of Japanese bonds outstanding is $Q_t(J)$ yen.

We use lowercase letters to denote the logarithm of the corresponding uppercase variables. For example, $b_{U,t} = \log(B_{U,t})$, $v_t = \log(V_t)$, $e_t = \log(E_t)$, $p_t(U) = \log(P_t(U))$, and $r_{t+1}(U) = \log(R_{t+1}(U))$. We use Δ to denote the first difference operator. For example, $\Delta b_{U,t+1} = b_{U,t+1} - b_{U,t}$ is the US inflation rate, and $\Delta e_{t+1} = e_{t+1} - e_t$ is exchange rate growth. We use bold letters to denote column vectors or matrices.

B. *Investors*

US Investors

US investors start with $A_{U,t-}$ dollars of wealth at time t, receive $Y_{U,t}$ dollars of endowment income, and spend $B_{U,t}C_{U,t}$ dollars on consumption.[1] Their wealth after consumption in dollars is

$$A_{U,t} = A_{U,t-} + Y_{U,t} - B_{U,t}C_{U,t}. \tag{1}$$

They allocate a share $w_{U,t}(J)$ of their wealth to Japanese bonds and the remaining share $1 - w_{U,t}(J)$ to US bonds. Their portfolio earns a gross real return

$$R_{U,t+1} = \left(R_{t+1}(U) + w_{U,t}(J) \left(\frac{R_{t+1}(J)E_{t+1}}{E_t} - R_{t+1}(U) \right) \right) \frac{B_{U,t}}{B_{U,t+1}} \tag{2}$$

in dollars from time t to $t+1$. The multiplication by E_{t+1}/E_t converts the Japanese bond return from yen to dollars. The multiplication by $B_{U,t}/B_{U,t+1}$ converts the nominal return to a real return. They consume their remaining wealth at time $t+1$. Thus, their intertemporal budget constraint is

$$C_{U,t+1} = R_{U,t+1}A_{U,t}. \tag{3}$$

US investors have constant relative risk aversion preferences. The preference parameter $\gamma > 0$ is relative risk aversion, and $\beta > 0$ is the subjective discount factor. Let the operator $\mathbb{E}_{U,t}$ be their subjective expectation at time t. They solve a consumption and portfolio choice

[1] In Appendix A, we specify $C_{U,t}$ as a constant elasticity of substitution aggregator over domestic and foreign goods and $B_{U,t}$ as the corresponding dual price index. We omit these equations here because the consumption and portfolio choice problem that follows does not depend on them.

problem at time t:

$$\max_{C_{U,t},w_{U,t}(J)} \frac{C_{U,t}^{1-\gamma}}{1-\gamma} + \beta\frac{\mathbb{E}_{U,t}\left[C_{U,t+1}^{1-\gamma}\right]}{1-\gamma}, \tag{4}$$

subject to the intertemporal budget constraint (3). The first-order conditions for consumption and portfolio choice are

$$\mathbb{E}_{U,t}\left[\beta\left(\frac{C_{U,t+1}}{C_{U,t}}\right)^{-\gamma}\frac{R_{t+1}(U)B_{U,t}}{B_{U,t+1}}\right] = 1, \tag{5}$$

$$\mathbb{E}_{U,t}\left[\beta\left(\frac{C_{U,t+1}}{C_{U,t}}\right)^{-\gamma}\frac{R_{t+1}(J)E_{t+1}B_{U,t}}{E_t B_{U,t+1}}\right] = 1. \tag{6}$$

Japanese Investors

Japanese investors start with $A_{J,t-}$ dollars of wealth at time t, receive $Y_{J,t}$ yen of endowment income, and spend $B_{J,t}C_{J,t}$ yen on consumption. Their wealth after consumption in dollars is

$$A_{J,t} = A_{J,t-} + E_t(Y_{J,t} - B_{J,t}C_{J,t}). \tag{7}$$

They allocate a share $w_{J,t}(U)$ of their wealth to US bonds and the remaining share $1-w_{J,t}(U)$ to Japanese bonds. Their portfolio earns a gross real return

$$R_{J,t+1} = \left(R_{t+1}(J)B_{J,t} + w_{J,t}(U)\left(\frac{R_{t+1}(U)E_t}{E_{t+1}} - R_{t+1}(J)\right)\right)\frac{B_{J,t}}{B_{J,t+1}} \tag{8}$$

in yen from time t to $t+1$. The multiplication by E_t/E_{t+1} converts the US bond return from dollars to yen. They consume their remaining wealth at time $t+1$. Thus, their intertemporal budget constraint is

$$C_{J,t+1} = R_{J,t+1}\frac{A_{J,t}}{E_t}. \tag{9}$$

Japanese investors have constant relative risk aversion preferences with the same preference parameters as US investors. They solve a consumption and portfolio choice problem at time t (i.e., equation (4) with the subscript J instead of U), subject to the intertemporal budget constraint (9). The first-order conditions for consumption and portfolio choice are

$$\mathbb{E}_{J,t}\left[\beta\left(\frac{C_{J,t+1}}{C_{J,t}}\right)^{-\gamma}\frac{R_{t+1}(J)B_{J,t}}{B_{J,t+1}}\right]=1, \tag{10}$$

$$\mathbb{E}_{J,t}\left[\beta\left(\frac{C_{J,t+1}}{C_{J,t}}\right)^{-\gamma}\frac{R_{t+1}(U)E_tB_{J,t}}{E_{t+1}B_{J,t+1}}\right]=1. \tag{11}$$

C. Optimal Consumption and Portfolio Choice

In Appendix A, we approximate equations (5) and (10) for optimal consumption as

$$r_{t+1}(n)=-\log(\beta)+\mathbb{E}_{n,t}[\Delta b_{n,t+1}]+\gamma\mathbb{E}_{n,t}[\Delta c_{n,t+1}]-\frac{\operatorname{Var}_{n,t}(\gamma\Delta c_{n,t+1}+\Delta b_{n,t+1})}{2}, \tag{12}$$

where $n=U$ for US investors and $n=J$ for Japanese investors. In the linearized Euler equation (12), the nominal bond return increases in expected inflation, increases in expected consumption growth due to intertemporal substitution, and decreases in the variance of consumption growth due to a precautionary motive.

We denote the mean and the variance of excess returns of US investors on Japanese bonds as

$$\mu_{U,t}(J)=\mathbb{E}_{U,t}[r_{t+1}(J)+\Delta e_{t+1}-r_{t+1}(U)], \tag{13}$$

$$\sigma^2_{U,t}(J)=\operatorname{Var}_{U,t}(r_{t+1}(J)+\Delta e_{t+1}-\Delta b_{U,t+1}). \tag{14}$$

We denote the mean and the variance of excess returns of Japanese investors on US bonds as

$$\mu_{J,t}(U)=\mathbb{E}_{J,t}[r_{t+1}(U)-\Delta e_{t+1}-r_{t+1}(J)], \tag{15}$$

$$\sigma^2_{J,t}(U)=\operatorname{Var}_{J,t}(r_{t+1}(U)-\Delta e_{t+1}-\Delta b_{J,t+1}). \tag{16}$$

In Appendix A, we show that equations (5) and (6) or equations (10) and (11) imply that investor i's optimal portfolio weight on the foreign bond $n\neq i$ is

$$w_{i,t}(n)=\frac{\mu_{i,t}(n)+\sigma^2_{i,t}(n)/2}{\gamma\sigma^2_{i,t}(n)}, \tag{17}$$

where $i=U$ for US investors and $i=J$ for Japanese investors. The mean-variance portfolio (17) is an approximate solution in discrete time but an exact solution in the continuous-time limit (Campbell and Viceira 2002, pp. 28–29).

Thus, we have two sets of equations that equivalently describe the optimal consumption and portfolio choice of US and Japanese investors. The first set consists of the Euler equations (5) and (6) for US investors and the Euler equations (10) and (11) for Japanese investors. The second set consists of the linearized Euler equation (12) for US and Japanese investors and the mean-variance portfolio (17) for US and Japanese investors. We will work with the second set for the remainder of this section.

D. Model of Short-Term Rates

We transform the linearized Euler equation into a model of short-term rates that we can estimate with macro data. Let $\boldsymbol{z}_t(n)$ be a vector of macro variables of country n, including a constant to capture the intercept, that investor n uses to form beliefs about the distribution of inflation and consumption growth. Let $\zeta_t(n)$ be a scalar that represents characteristics unobserved by the econometrician that investor n uses to form beliefs about the same. We model the right side of equation (12) as a function of the observed and unobserved characteristics:

$$p_t(n) = -r_{t+1}(n) = \boldsymbol{\Pi}'\boldsymbol{z}_t(n) + \zeta_t(n). \tag{18}$$

E. Asset Demand

We transform the mean-variance portfolio into an asset demand function that we can estimate with portfolio holdings data. Using the identity $r_{t+1}(J) - r_{t+1}(U) = p_t(U) - p_t(J)$, we model the expected excess return of US investors on Japanese bonds as

$$\mu_{U,t}(J) = p_t(U) - p_t(J) - \Theta(e_t - v_t). \tag{19}$$

A high real exchange rate $e_t - v_t$ predicts depreciation of the nominal exchange rate under purchasing power parity, so the coefficient $\Theta \geq 0$. Similarly, we model the expected excess return of Japanese investors on US bonds as

$$\mu_{J,t}(U) = p_t(J) - p_t(U) + \Theta(e_t - v_t). \tag{20}$$

The real exchange rate enters with the oppositive sign in equations (19) and (20) because US investors care about returns in dollars and Japanese investors care about returns in yen.

Let $\boldsymbol{x}_{i,t}(n)$ be a vector of observed characteristics that investor i uses to form beliefs about the variance of excess returns on bond n, including a constant to capture the intercept. Let $\psi_{i,t}(n)$ be a scalar that represents characteristics unobserved by the econometrician that investor i uses to form beliefs about the same. We model the variance of excess returns on bond n as a function of the observed and unobserved characteristics:

$$\sigma_{i,t}^2(n) = \exp(-\boldsymbol{\Psi}'\boldsymbol{x}_{i,t}(n) - \psi_{i,t}(n)). \tag{21}$$

We motivate our assumption with the fact that international bond returns have a factor structure and that expected returns and factor loadings depend on asset characteristics (Asness et al. 2013; Dahlquist and Hasseltoft 2013; Jotikasthira et al. 2015).

Heterogeneous beliefs imply that investors have heterogeneous portfolios in equilibrium. Substituting equation (19) or (20) and equation (21) in the mean-variance portfolio (17), investor i's portfolio weight on the foreign bond $n \neq i$ is

$$w_{i,t}(n) = \frac{\mu_{i,t}(n)\exp(\boldsymbol{\Psi}'\boldsymbol{x}_{i,t}(n) + \psi_{i,t}(n)) + 1/2}{\gamma}. \tag{22}$$

Then the portfolio weight on the domestic bond is $w_{i,t}(i) = 1 - w_{i,t}(n)$. Asset demand (22) increases in the expected excess return $\mu_{i,t}(n)$ or equivalently decreases in the bond price. Asset demand also increases in observed characteristics $\boldsymbol{x}_{i,t}(n)$ that relate to lower risk.[2] The observed characteristics could include the bilateral distance to capture gravity and an indicator variable for domestic ownership to capture home bias. Asset demand also increases in unobserved characteristics $\psi_{i,t}(n)$, which we call latent demand, that relate to lower risk. Latent demand is a residual term, which ensures that the asset demand function matches the portfolio holdings data.

Although we derive asset demand (22) from a traditional model of consumption and portfolio choice, we deviate from the traditional approach in an important way. We treat the demand elasticities to prices and observed characteristics as free parameters, instead of imposing theoretically implied elasticities that are rigid moments of returns. Under heterogeneous beliefs, we have no reason to believe that investor beliefs coincide with the estimated moments of returns. Moreover, theoretically implied elasticities, based on models like the capital asset pricing model, are several orders of magnitude greater than the empirical estimates (Petajisto 2009).

F. Market Clearing

Market clearing for consumption goods is

$$Y_{U,t} + E_t Y_{J,t} = B_{U,t} C_{U,t} + E_t B_{J,t} C_{J,t}. \tag{23}$$

[2] Asset demand could depend on asset characteristics due to microfoundations other than heterogeneous beliefs about the variance of returns. They include heterogeneous beliefs about higher moments of returns, hedging demand from income risk (Koijen et al. 2023), and direct tastes for asset characteristics (Fama and French 2007).

That is, total endowment income equals total consumption expenditure. Substituting the budget constraints of US investors (1) and Japanese investors (7) in equation (23), we rewrite market clearing for consumption goods as a balance of payments in the financial accounts:

$$A_{U,t} - A_{U,t-} + A_{J,t} - A_{J,t-} = 0. \tag{24}$$

Market clearing for bond n is

$$P_t(n)Q_t(n) = A_{U,t}w_{U,t}(n) + A_{J,t}w_{J,t}(n), \tag{25}$$

where $n = U$ for US bonds and $n = J$ for Japanese bonds. The left side is the supply of bonds in dollars. The right side is the demand for bonds in dollars, which is wealth times the portfolio weight aggregated across US and Japanese investors.

Thus, we have market clearing for consumption goods, US bonds, and Japanese bonds. They determine the exchange rate E_t, the US bond price $P_t(U)$, and the Japanese bond price $P_t(J)$. We can describe the equilibrium in several equivalent ways. For example, we have two equations for the model of short-term rates (18) in the United States and Japan, derived from the consumption Euler equations. The third equation is market clearing (25) for Japanese bonds, where equation (22) is the asset demand of US and Japanese investors. Since the consumption goods market and the Japanese bond market clear, the US bond market also clears by Walras's law.

G. Relation to the Literature

Our two-country model is closest to a group of papers that fix the domestic and foreign interest rates and determine the exchange rate by market clearing for either consumption goods or foreign bonds. Kouri (1983) fixes the domestic and foreign interest rates and determines the exchange rate by the balance of payments in the financial accounts (24). Blanchard et al. (2005) fix the domestic and foreign interest rates and determine the exchange rate by market clearing for foreign bonds (25). Gabaix and Maggiori (2015) fix the domestic and foreign interest rates and write market clearing for consumption goods (23) as $B_{U,t}C_{U,t} - Y_{U,t} = A_{J,t} - A_{J,t-}$. Furthermore, they assume segmentation in bond markets so that they replace $A_{J,t} - A_{J,t-}$ with the financiers' demand for US bonds. Relative to this literature, we allow interest rates to depend on macro variables in equation (18) and extend the model to multiple countries and asset classes.

A different group of papers replace market clearing for consumption goods with a flow equation for market clearing in the foreign exchange market to determine the exchange rate (Hau and Rey 2006; Gourinchas et al. 2022). Hau and Rey (2006) fix the domestic and foreign interest rates and have market clearing for domestic and foreign equity. Gourinchas et al. (2022) specify exogenous processes for the domestic and foreign short-term rates and have market clearing for the term structure of interest rates.

II. Global Demand System

To match international portfolio holdings, we extend the asset demand system to multiple countries and three asset classes: short-term debt, long-term debt, and equity. The model of short-term rates (18) extends to multiple countries without modification. However, we must modify asset demand (22) to fit portfolio holdings across multiple countries and asset classes. We develop a nested logit model with substitution across countries in the inner nest and across asset classes in the outer nest, generalizing the logit model of asset demand (Koijen and Yogo 2019).

A. Asset Markets

We index the issuer countries as $n = 1, \dots, N$. For each country, we index the three asset classes as short-term debt ($l = S$), long-term debt ($l = L$), and equity ($l = E$). $P_t(n, l)$ is the price of asset class l in country n at time t. $Q_t(n, l)$ is the quantity in local currency of asset class l in country n at time t. For debt, $P_t(n, l)$ is the price per unit of face value, and $Q_t(n, l)$ is the face value of debt outstanding in local currency. For equity, $P_t(n, l)$ is market-to-book equity, and $Q_t(n, l)$ is the book value of equity outstanding in local currency. $E_t(n)$ is the nominal exchange rate in US dollars per country n's currency unit at time t. $V_t(n)$ is the relative price index (i.e., the purchasing power parity conversion factor) in US dollars per country n's currency unit at time t. Thus, $E_t(n)/V_t(n)$ is the real exchange rate.

We clarify the notation through an example of Japanese long-term debt. $P_t(n, L)$ is the price in yen per yen of face value (equivalently, US dollars per dollar of face value). $Q_t(n, L)$ is the face value of debt outstanding in yen. $E_t(n)$ is the exchange rate in US dollars per yen. Thus, $P_t(n, L)Q_t(n, L)$ is the market value of debt outstanding in yen, and $P_t(n, L)E_t(n)Q_t(n, L)$ is the market value of debt outstanding in US dollars.

B. Expected Returns

We index the investor countries as $i = 1, \dots, I$. We extend the model of expected returns (i.e., equations (19) and (20)) to I investor countries, N issuer countries, and three asset classes. We model expected returns as the predicted values from a predictive regression of future returns on the asset price and the real exchange rate.

Let $r_{t+1}(n, l)$ be log nominal return in local currency on asset class l in country n from time t to $t + 1$. Then log return in US dollars is $r_{t+1}(n, l) + \Delta e_{t+1}(n)$. For each asset class, we estimate a predictive regression for log returns in US dollars:

$$r_{t+1}(n,l) + \Delta e_{t+1}(n) = -\theta_l p_t(n,l) - \Theta_l(e_t(n) - v_t(n)) + \chi_{n,l} + \nu_{t+1}(n,l), \tag{26}$$

where $\chi_{n,l}$ are country fixed effects. Log asset price $p_t(n,l)$ is minus maturity times log yield for debt and log market-to-book for equity, so the coefficient $\theta_l \geq 0$ by mean reversion. A high log real exchange rate $e_t(n) - v_t(n)$ predicts depreciation of the nominal exchange rate under purchasing power parity, so the coefficient $\Theta_l \geq 0$.

We assume that investors care about returns in their local currency for the purposes of portfolio choice. The predicted values from predictive regression (26) are expected returns in US dollars. We construct the expected excess return in investor i's local currency as

$$\mathbb{E}_t[r_{t+1}(n,l) + \Delta e_{t+1}(n) - r_{t+1}(i,S) - \Delta e_{t+1}(i)] = \mu_{i,t}(n,l) + \chi_{n,l} - \chi_{i,S}, \tag{27}$$

where

$$\mu_{i,t}(n,l) = -\theta_l p_t(n,l) - \Theta_l(e_t(n) - v_t(n)) + \theta_S p_t(i,S) + \Theta_S(e_t(i) - v_t(i)). \tag{28}$$

Consider an example of Japanese investors holding UK equity, who care about returns in yen. Since $\Delta e_{t+1}(n) - \Delta e_{t+1}(i)$ is the percent change in the yen-pound exchange rate, equation (28) is the expected UK equity return in yen minus the Japanese short-term rate in yen.

C. Asset Demand

Each investor i allocates wealth $A_{i,t}$ in US dollars at time t across three asset classes in N issuer countries. As we describe in Section III, these inside assets are exclusively in local currency. Therefore, equation (28) accurately reflects the expected return on an inside asset in local currency. The investor could also allocate wealth to an outside asset (indexed as $n = 0$) for each asset class. The outside asset consists of assets issued outside of the N countries and foreign currency assets issued by one of the N countries.

We write investor i's portfolio weight on asset class l in country n at time t as

$$w_{i,t}(n,l) = w_{i,t}(n|l) w_{i,t}(l). \tag{29}$$

The right side is the product of the portfolio weight on country n within asset class l and the aggregate portfolio weight on asset class l. The portfolio weights sum to one within each asset class: $\sum_{n=0}^{N} w_{i,t}(n|l) = 1$. The aggregate portfolio weights sum to one across all asset classes: $\sum_{l \in \{S,L,E\}} w_{i,t}(l) = 1$. Let $O_{i,t} = \sum_{l \in \{S,L,E\}} A_{i,t} w_{i,t}(0,l)$ be outside wealth in US dollars. We write investor i's wealth at time t as

$$A_{i,t} = \frac{O_{i,t}}{1 - \sum_{l \in \{S,L,E\}} \sum_{n=1}^{N} w_{i,t}(n,l)}. \tag{30}$$

In Appendix A, we derive a logit model of asset demand from a consumption and portfolio choice model, following Koijen and Yogo (2019). In what follows, we generalize the logit model to a nested logit model to allow for imperfect substitution across asset classes. The inner nest $w_{i,t}(n|l)$ in equation (29) models how an investor substitutes across countries within an asset class. The outer nest $w_{i,t}(l)$ models how an investor substitutes across asset classes.

Demand within Asset Class

Investor i's portfolio weight on country n within asset class l at time t is

$$w_{i,t}(n|l) = \frac{\delta_{i,t}(n,l)}{1 + \sum_{m=0}^{N} \delta_{i,t}(m,l)}, \tag{31}$$

where

$$\log(\delta_{i,t}(n,l)) = \lambda_l \mu_{i,t}(n,l) + \boldsymbol{\Lambda}_l' \boldsymbol{x}_{i,t}(n) + \epsilon_{i,t}(n,l). \tag{32}$$

Asset demand depends on the expected excess return $\mu_{i,t}(n,l)$, a vector of asset characteristics $\boldsymbol{x}_{i,t}(n)$, and latent demand $\epsilon_{i,t}(n,l)$. We index the coefficients λ_l and $\boldsymbol{\Lambda}_l$ by l to allow for heterogeneous demand elasticities across asset classes. By the budget constraint, investor i's outside portfolio weight within asset class l at time t is

$$w_{i,t}(0|l) = \frac{1}{1 + \sum_{m=0}^{N} \delta_{i,t}(m,l)}. \tag{33}$$

In every portfolio choice model, asset allocation depends on differences in expected returns across assets. The expected excess return $\mu_{i,t}(n,l)$ is a combination of the asset price and the real exchange rate that best predicts returns. That is, we impose a single index restriction on the asset price and the real exchange rate to respect the economic reason that these two variables enter asset demand. Each investor cares about returns in its local currency, which explains the index i in $\mu_{i,t}(n,l)$. The expected UK equity return for US investors in US dollars is different from the expected UK equity return for Japanese investors in yen.

Asset allocation also depends on differences in perceived risk across assets, which we model through the asset characteristics and latent demand. We index the asset characteristics not only by issuer n but also by investor i to allow for bilateral variables such as the bilateral distance and an indicator variable for domestic ownership. Thus, investors have heterogeneous beliefs about risk for the same asset. For example, investors could believe that farther countries have higher risk because of informational frictions that increase in the bilateral distance. Similarly, latent demand represents characteristics unobserved by the econometrician, which capture heterogeneous beliefs about risk across investors and assets.

Demand across Asset Classes

Investor i's aggregate portfolio weight on asset class l at time t is

$$w_{i,t}(l) = \frac{\left(1 + \sum_{m=0}^{N} \delta_{i,t}(m,l)\right)^{\rho_l} \exp(\alpha_l + \xi_{i,t}(l))}{\sum_{k \in \{S,L,E\}} \left(1 + \sum_{m=0}^{N} \delta_{i,t}(m,k)\right)^{\rho_k} \exp(\alpha_k + \xi_{i,t}(k))}. \tag{34}$$

The first term inside the parentheses in the numerator, which is also the denominator in the inner nest (31), is the "inclusive value" in a nested logit model. The parameter $\rho_l \in [0,1]$ determines the elasticity of the aggregate portfolio weight to the inclusive value.

To understand the role of the inclusive value, suppose that the demand for short-term debt increases in its expected return (i.e., $\lambda_S > 0$). A decrease in short-term debt prices across several countries makes short-term debt more attractive as an asset class, reflected by an increase in its inclusive value. The outer nest (34) then implies an increase in the aggregate portfolio weight on short-term debt and a decrease in the aggregate portfolio weights on long-term debt and equity. Thus, the inclusive value connects changing asset prices and characteristics in the inner nest to respective changes in the aggregate portfolio weights in the outer nest. Higher values of ρ_l imply stronger substitution effects, so that a demand shock in the inner nest has stronger effects on the demand for other asset classes.

In addition to the inclusive value, equation (34) depends on asset-class fixed effects α_l and asset-class latent demand $\xi_{i,t}(l)$. Asset-class latent demand represents characteristics unobserved by the econometrician, which capture heterogeneous beliefs about risk across investors and asset classes. Because the budget constraint implies that there are only two degrees of freedom, we normalize $\alpha_E + \xi_{i,t}(E) = 0$ for equity.

Special Cases

When $\rho_l = 1$ for all asset classes in equation (34), we have a logit model with perfect substitution across asset classes. Investor i's portfolio weight on asset class l in country n at time t simplifies to

$$w_{i,t}(n,l) = \frac{\delta_{i,t}(n,l)}{3 + \sum_{k \in \{S,L,E\}} \sum_{m=0}^{N} \delta_{i,t}(m,k)}. \tag{35}$$

In this equation, we normalize $\alpha_l + \xi_{i,t}(l) = 0$ because asset-class latent demand is not separately identified from latent demand within asset classes.

When $\rho_l = 0$ for all asset classes in equation (34), we have no substitution across asset classes. The portfolio weight on asset class l in country n at time t simplifies to

$$w_{i,t}(n,l) = \frac{\delta_{i,t}(n,l)}{1 + \sum_{m=0}^{N} \delta_{i,t}(m,l)} \frac{\exp(\alpha_l + \xi_{i,t}(l))}{\sum_{k \in \{S,L,E\}} \exp(\alpha_k + \xi_{i,t}(k))}. \tag{36}$$

In this case, the allocation across asset classes does not depend on the inclusive value, ruling out substitution effects. Nevertheless, a demand shock in the inner nest could still affect the demand for other asset classes through the investors' wealth (30).

D. Market Clearing

We have a system of $3N$ market clearing equations for the three asset classes times N countries. Market clearing for each asset class l in country n at time t is

$$P_t(n,l)E_t(n)Q_t(n,l) = \sum_{i=1}^{I} A_{i,t} w_{i,t}(n,l). \tag{37}$$

The left side is the supply or the market value in US dollars. The right side is the aggregate demand in US dollars, which is the sum of wealth times the portfolio weight across all investors. The portfolio weight depends on all exchange rates and asset prices through equations (29), (31), and (34). By equation (30), wealth also depends on all exchange rates and asset prices through the portfolio weights.

In addition to the $3N$ market clearing equations, we have N equations for the model of short-term rates (18), derived from the consumption Euler equations. We drop the market clearing equation for US short-term debt, which is redundant by Walras's law. By defining all exchange rates to be US dollars per local currency unit, we normalize the exchange rate for the US dollar with itself to be one. Thus, we have a system of $4N-1$ equations in $N-1$ exchange rates and $3N$ asset prices in the absence of currency unions or fixed exchange rates.

We have $N = 37$ issuer countries in the empirical application. However, ten of the 37 countries are in the euro area. In addition, the Hong Kong dollar is pegged to the US dollar, and the Danish krone is pegged to the euro. We assume that these two exchange rates remain pegged in the counterfactual analysis. Thus, we have a system of $4N-23$ equations in $N-12$ exchange rates, $N-11$ short-term debt prices, N long-term debt prices, and N equity prices. In the empirical applications, we numerically verify the existence of equilibrium. Although we cannot prove the uniqueness of equilibrium, we do not find any cases of multiplicity with different starting values.[3]

Let $\boldsymbol{e}_t$ be a column vector of dimension $N - 12$, whose nth element is log exchange rate $e_t(n)$. Let $\boldsymbol{p}_t$ be a matrix of dimension $(3N - 11) \times 3$, whose (n, l)th element is log asset price $p_t(n, l)$. The asset demand system and market clearing define an implicit function for exchange rates and asset prices:

$$\begin{bmatrix} \boldsymbol{e}_t \\ \boldsymbol{p}_t \end{bmatrix} = \boldsymbol{m}(\boldsymbol{Q}_t, \boldsymbol{O}_t, \boldsymbol{X}_t, \boldsymbol{\epsilon}_t, \boldsymbol{\xi}_t, \boldsymbol{\zeta}_t). \tag{38}$$

On the right side, $\boldsymbol{Q}_t$ is a matrix of dimension $N \times 3$, whose (n, l)th element is asset quantity $Q_t(n, l)$. $\boldsymbol{O}_t$ is a vector of dimension I, whose ith element is outside wealth $O_{i,t}$. $\boldsymbol{X}_t$ is a matrix that stacks the observed characteristics $\boldsymbol{x}_{i,t}(n)$ that enter asset demand, log relative price index $v_t(n)$, and the macro variables $\boldsymbol{z}_t(n)$ that enter the model of short-term rates. The matrices $\boldsymbol{\epsilon}_t$, $\boldsymbol{\xi}_t$, and $\boldsymbol{\zeta}_t$ represent latent demand for the portfolio weights within asset class, the aggregate portfolio weights across asset classes, and the model of short-term rates, respectively.

III. Data on International Portfolio Holdings and Asset Prices

We summarize the data construction of international portfolio holdings, asset prices, and asset characteristics. We refer the reader to Appendix B for further details about the data construction. We also present reduced-form facts that motivate the formal analysis in the subsequent sections.

A. Data Construction

International Portfolio Holdings

We construct portfolio holdings by year, investor country, issuer county, and asset class for 37 countries and other countries (i.e., the rest of the world) for the period 2003 to 2020. The 37 countries consists of all 22 countries in the MSCI World Index and 15 of 21 countries in the MSCI Emerging Markets Index. As we describe in Appendix B, the data coverage improves over time from 31 countries in 2003 to 37 countries in 2020. The three asset classes are short-term debt (i.e., maturity of one year or less), long-term debt (i.e., maturity greater than one year), and equity. Debt includes both government and corporate debt.

We proceed in two steps. First, we construct the total amounts outstanding by year, issuer country, and asset class. Our data sources are the Organisation for Economic Cooperation and Development (2003–2020), the Bank for International Settlements (2003–2020),

[3]For the logit model of asset demand, $\max\{-\lambda_l \theta_l, -\lambda_l \Theta_l\} < 1$ is sufficient for the existence and uniqueness of equilibrium (Koijen and Yogo 2019, Proposition 2). The estimated demand system satisfies this condition.

and the World Bank (2003–2020). We use the available information on the currency composition of international debt securities (Bank for International Settlements 2003–2020) to separate local and foreign currency debt. To account for investments through tax havens, we restate the total amounts outstanding from the issuer's residency to nationality, based on the restatement matrices of the Global Capital Allocation Project (Coppola et al. 2021).

Second, we construct foreign portfolio holdings by year, investor country, issuer country, and asset class. Our data sources are Forms SHC/SHCA (U.S. Department of the Treasury 2003–2020) for US investors and the Coordinated Portfolio Investment Survey (International Monetary Fund 2003–2020a) for the other investor countries. We use the available information on the currency composition to separate local and foreign currency assets. We restate the foreign portfolio holdings from the issuer's residency to nationality, based on the restatement matrices of the Global Capital Allocation Project. We then merge these data with the total amounts outstanding from the first step. We construct the domestic portfolio holding as the total amount outstanding minus the sum of foreign portfolio holdings. This construction implies that the domestic portfolio holdings contain the central bank holdings (e.g., the Federal Reserve's holdings of US Treasury debt).

In addition to the 37 investor countries, we treat the aggregate portfolio holdings of foreign exchange reserves and other countries as separate investor units. Foreign exchange reserves represent the foreign portfolio holdings of central banks (e.g., the Bank of Japan's holdings of US Treasury debt), which the International Monetary Fund (2003–2020a) aggregates across countries for confidentiality. Other countries represent the foreign portfolio holdings outside of the 37 investor countries and foreign exchange reserves.

We construct the portfolio holdings so that the inside assets in the 37 issuer countries are exclusively in local currency. The outside asset for each asset class is the sum of assets issued outside of the 37 countries and foreign currency assets issued by one of the 37 countries. We need to aggregate the foreign currency assets as part of the outside asset because our data sources do specify the currency when an asset is in foreign currency.

Asset Prices

We use year-end values of exchange rates and asset prices to align with the year-end values of portfolio holdings. Exchange rates are from the International Monetary Fund (2003–2020b). The purchasing power parity conversion factors for GDP in current international dollars, which we refer to as the relative price indices, are from the World Bank (2003–2020). Throughout the paper, both exchange rates and the relative price indices are in US dollars per local currency unit. Thus, the real exchange rate is the nominal exchange rate divided by the relative price index. Ten of the 37 countries are in the euro area. In addition, the

Hong Kong dollar is pegged to the US dollar, and the Danish krone is pegged to the euro. Therefore, the sample contains 25 independent exchange rates relative to the US dollar.

The short-term rates are the three-month interbank rates from Datastream (Refinitiv 2003–2020). The sample contains 26 independent short-term rates, accounting for the euro area and the two currency pegs. We construct the long-term yields, based on the ten-year benchmark government bond yields from Datastream. We estimate a Nelson and Siegel (1987) zero-coupon yield curve for each country, assuming that the ten-year benchmark yield is the par yield. Throughout the paper, the long-term yield refers to the five-year zero-coupon yield, which we assume is representative of international long-term debt holdings.[4] Equity prices are market-to-book equity from the MSCI (2003–2020). Equity returns on the MSCI Country Indexes are from Datastream.

Asset Characteristics

For the asset demand estimation, we must specify asset characteristics that explain portfolio choice across countries. The macro variables are log GDP at purchasing power parity, log GDP per capita at purchasing power parity, inflation, equity volatility, and sovereign debt ratings. We convert the rating to a continuous measure equal to -1 times the ten-year default rate, so that a higher measure implies a higher rating. We refer to Appendix B for further details about the construction of these variables.

To capture gravity in international portfolios, we use the simple distance between investor and issuer countries, defined as the weighted distance between the most populous cities, from the GeoDist Database (Mayer and Zignago 2011). For foreign exchange reserves and other countries (i.e., the rest of the world), we cannot define their bilateral distance with issuer countries. For these investor units, we set the bilateral distance to zero and include indicator variables to allow for different intercepts. We include an indicator variable for domestic ownership to capture home bias. Finally, we include year fixed effects to capture common time-series variation in latent demand.

Data Limitations

We discuss several data limitations that future research could address with improved public data or nonpublic data. We would like to disaggregate the foreign exchange reserves and assign them to the respective investor countries. Ito and McCauley (2020), who hand collect the currency composition of foreign exchange reserves for nearly 60 central banks, is an important step toward this effort. However, their data are shares (not levels) in US

[4]The simplifying assumption is that the three-month rate and the five-year zero-coupon yield capture the level and the slope of the term structure of interest rates. US investors' portfolio of foreign long-term debt has a median remaining maturity of about six years, which is stable over time (U.S. Department of the Treasury 2021, Exhibit 8).

dollars, euros, Japanese yen, and British pounds. For our application, we would also need the overall size of foreign exchange reserves for each central bank.

We cover all portfolio investment in debt securities and common equity. We do not cover other investments including fund shares, bank deposits, and foreign direct investment. Based on currently available data, we cannot disaggregate fund shares into asset classes and restate them from residency to nationality accounting (Coppola et al. 2021). The Bank for International Settlements publishes bilateral bank liabilities by residency. Future research needs to restate these data from residency to nationality accounting and to combine them with hand-collected data on domestic bank liabilities. Damgaard et al. (2019) undertake the difficult task of restating foreign direct investment from residency to nationality accounting for 2009 to 2017. Future research needs to expand the sample period and combine these data with domestic real investment. Moreover, foreign direct investment should most likely be a separate asset class from public equity, and we encounter a difficult issue of how to measure its price.

We do not adjust the debt holdings for currency hedging. Du and Huber (2023), who hand collect the US dollar hedging of foreign institutions, is an important step toward this effort. They find that insurers hedged 44 percent, pension funds hedged 35 percent, and mutual funds hedged 21 percent of their US dollar exposure in 2020. Whether we need to adjust the debt holdings at the country level depends on the counterparty in the currency hedge. If a Japanese insurer holds a US dollar bond that is perfectly hedged, it essentially holds a Japanese yen bond. However, if the counterparty is a Japanese institution, we do not need to adjust the debt holdings at the country level. The data sources in Du and Huber (2023) do not contain information about the counterparties. This measurement issue is important to resolve in future research with the use of nonpublic data.

B. Summary of Global Financial Markets

Table 1 summarizes financial markets across the 37 countries and three asset classes in 2020. The US short-term debt market was $5.489 trillion, of which domestic investors held 92 percent. The US long-term debt market was $41.070 trillion, of which domestic investors held 84 percent. The US equity market was $55.623 trillion, of which domestic investors held 87 percent. The domestic share is consistently high across countries and asset classes, implying that home bias is a key feature of the data.

Foreign central banks hold a significant share of developed market debt in foreign exchange reserves. However, foreign central banks do not hold much emerging market debt, developed market equity, or emerging market equity. In 2020, foreign central banks held 4 percent of US short-term debt and 5 percent of US long-term debt. Foreign exchange reserves account for a significant share of euro-area debt. For example, foreign central banks held 34 percent of German short-term debt and 13 percent of German long-term debt. The large size of foreign exchange reserves suggests that foreign central banks play an important role in managing exchange rates and the term structure of interest rates globally.

Table 2 reports the top ten investors by asset class in 2020. Unsurprisingly, the largest developed countries are the largest investors in each asset class. The largest investor is the United States with $5.423 trillion in short-term debt, $38.283 trillion in long-term debt, and $56.324 trillion in equity. The second largest investor is Japan with $1.444 trillion in short-term debt, $16.206 trillion in long-term debt, and $12.424 trillion in equity. Foreign exchange reserves are a large investor unit in debt markets. Foreign central banks held $1.025 trillion of short-term debt and $4.952 trillion of long-term debt.

C. Relative Asset Prices Versus Quantities

Figure 1 is a scatter plot of the relative short-term debt prices versus quantities for the euro area, Japan, Switzerland, and the United Kingdom. The vertical axis is the US short-term rate minus each region's short-term rate. The horizontal axis is each region's log face value of short-term debt in US dollars minus log face value of US short-term debt (i.e., $e_t(n) + q_t(n, S) - q_t(U, S)$). We subtract the time-series mean from each axis. Thus, the relative short-term debt quantities are in percent deviation from the average year (i.e., 0.4 means 40% higher than average). The scatter plot suggests a downward-sloping demand curve for short-term debt. When the relative supply of Japanese short-term debt is high, its relative price is low.

Figure 2 repeats the same exercise for long-term debt in Germany, Japan, Switzerland, and the United Kingdom. The vertical axis is the US long-term yield minus each country's long-term yield. The horizontal axis is each country's log face value of long-term debt in US dollars minus log face value of US long-term debt (i.e., $e_t(n) + q_t(n, L) - q_t(U, L)$). The scatter plot suggests a downward-sloping demand curve for long-term debt. Krishnamurthy and Vissing-Jørgensen (2012) find a negative relation between the prices and quantities of US Treasury debt relative to AAA corporate debt. We extend the evidence to an international context, finding a negative relation between the prices and quantities of US Treasury debt relative to the long-term debt of major currencies.

Figures 3 repeats the same exercise for equity in Germany, Japan, Switzerland, and the United Kingdom. The vertical axis is each country's log market-to-book equity minus the US log market-to-book equity (i.e., $p_t(n, E) - p_t(U, E)$). The horizontal axis is each country's log book equity in US dollars minus the US log book equity (i.e., $e_t(n) + q_t(n, E) - q_t(U, E)$). The scatter plot suggests a downward-sloping demand curve for equity, except for Germany and Japan. In general, we do no expect to see a downward-sloping demand curve from a scatter plot because the demand curve could be shifting over time. The fact that we can decipher a downward-sloping demand curve suggests that it is relatively stable over time, for the four major currencies during our sample period.

The slope of the demand curve quantifies the degree to which investors view the assets of different countries to be close substitutes. The slope would be virtually flat if the assets of different countries were near-perfect substitutes. In contrast, the steepness of the slopes in Figures 1–3 suggests that assets of different countries are imperfect substitutes. However, this evidence is only suggestive because the actual demand curve could be shifting over time. We need proper identification to estimate the demand elasticities, which we address in the next section.

IV. Asset Demand Estimation

We estimate the asset demand system in four steps. First, we estimate the predictive regression (26) to construct expected returns. Second, we estimate the demand within asset class, which is the inner nest of the nested logit model. Third, we estimate the demand across asset classes, which is the outer nest of the nested logit model. Finally, we estimate the model of short-term rates (18).

A. Expected Returns

We estimate the predictive regression (26) for each asset class. For short-term debt, we impose the approximation that the annual return is four times the three-month yield (i.e., $r_{t+1}(n, S) = -4p_t(n, S)$). Then the predictive regression simplifies to the exchange rate growth on log real exchange rate. We use the predicted values from the predictive regression to construct expected returns in each investor's local currency, according to equation (28).

Table 3 reports estimates of the predictive regressions. A high log asset price predicts low returns for long-term debt and equity. A high real exchange rate (in US dollars per local currency unit) predicts low returns in US dollars for all asset classes. For equity, the estimated coefficient is -0.15 on log market-to-book equity and -0.54 on log real exchange rate. These coefficients imply that expected equity returns decrease by 15 basis points per one percent increase in market-to-book equity and 54 basis points per one percent increase in the real exchange rate.

B. Demand within Asset Class

Estimating Equations

Dividing equation (31) by equation (33) and taking logarithms, we have

$$\log\left(\frac{w_{i,t}(n|l)}{w_{i,t}(0|l)}\right) = \lambda_l \mu_{i,t}(n,l) + \boldsymbol{\Lambda}_l' \boldsymbol{x}_{i,t}(n) + \epsilon_{i,t}(n,l). \tag{39}$$

We have a panel regression model for each asset class l, where the observations are investor i's portfolio weight on country n relative to the outside asset in year t. The coefficients λ_l and $\boldsymbol{\Lambda}_l$ vary across asset classes. However, we assume that they are constant across investors because of the limited sample size. Equation (39) says that the demand for Japanese long-term debt relative to UK long-term debt depends on their relative characteristics. An investor substitutes from Japanese to UK long-term debt if the characteristics of UK long-term debt become relatively more attractive (e.g., higher rating).

Identifying Assumptions

Asset demand estimation requires identifying assumptions because exchange rates and asset prices are endogenous with latent demand. Our starting point is the assumption that asset characteristics are exogenous, following the tradition of asset pricing in endowment economies (Lucas 1978). The ultimate goal, beyond the scope of this paper, is to endogenize the macro variables together with exchange rates and asset prices. Doing so for all countries and asset classes is a formidable task that is beyond the current scope of international macro models (e.g., Engel and Matsumoto 2009; Devereux and Sutherland 2011; Heathcote and Perri 2013).

To explain the identification strategy, we rewrite market clearing (37) as

$$P_t(n,l)\frac{E_t(n)}{V_t(n)} = \left(\underbrace{A_{i,t}w_{i,t}(n,l)}_{i\text{'s demand}} + \underbrace{\sum_{j\neq i} A_{j,t}w_{j,t}(n,l)}_{\text{other investors' demand}}\right)\underbrace{\frac{1}{V_t(n)Q_t(n,l)}}_{\text{supply}}. \tag{40}$$

On the left side is the price of asset class l in country n times the real exchange rate. On the right side, we split the aggregate demand into investor i's demand and the other investors' demand. Investor i faces a higher asset price and/or a higher real exchange if the other investors' demand shifts positively. From investor i's perspective, a positive shift in the other investors' demand is a negative shift in the residual supply, which identifies investor i's demand elasticity. Thus, identification requires plausibly exogenous shifts in the other investors' demand.

The identification strategy is based on three observations. First, we could estimate asset demand (39) based on the cross-sectional variation in portfolio weights and expected returns. Second, the gravity effect generates an inelastic and time-invariant component of portfolio weights across countries. Third, longstanding differences in GDP and population across countries generates an inelastic and time-invariant component of supply.

To construct the instrument, we first estimate a gravity equation on the cross-section of portfolio holdings. Let $D_i(n)$ be the bilateral distance between investor i and issuer n. For each asset class l, we estimate a panel regression:

$$\log\left(\frac{w_{i,t}(n|l)}{w_{i,t}(0|l)}\right) = \Upsilon_l D_i(n) + \upsilon_l + \tau_{l,t} + \eta_{i,t}(n,l), \tag{41}$$

where υ_l is the common intercept and $\tau_{l,t}$ represents year fixed effects. This model is equation (39) with only a subset of the observed characteristics (i.e., the bilateral distance and year fixed effects). Let

$$\widehat{\delta}_i(n,l) = \exp\left(\widehat{\Upsilon}_l D_i(n) + \widehat{\upsilon}_l\right), \tag{42}$$

where $\widehat{\Upsilon}_l$ and $\widehat{\upsilon}_l$ represent the corresponding estimated coefficients. Let $\widehat{w}(l)$ be the mean portfolio weight on asset class l, estimated from a pooled regression over investors and time. We construct investor i's predicted portfolio weight on asset class l in country n in year t as

$$\widehat{w}_i(n,l) = \frac{\widehat{\delta}_i(n,l)}{1+\sum_{m=0}^{N}\widehat{\delta}_i(m,l)}\widehat{w}(l). \tag{43}$$

We then estimate the inelastic and time-invariant component of supply. For each asset class, we estimate a panel regression of log asset quantity (i.e., $v_t(n) + q_t(n,l)$) on log GDP at purchasing power parity, log population, and year fixed effects. We refer to the predicted value of this regression with a common intercept (i.e., without the year fixed effects) as the predicted log supply, which we denote as $v_t(n) + \widehat{q}_t(n,l)$.

We then construct an instrument for $\mu_{i,t}(n,l)$ in asset demand (39) as

$$\mathrm{IV}_{i,t}(n,l) = \underbrace{\log\left(\sum_{j\neq i}\frac{O_{j,t}\widehat{w}_j(n,l)}{1-\sum_{l\in\{S,L,E\}}\sum_{n=1}^{N}\widehat{w}_j(n,l)}\right)}_{\text{predicted log demand}} - \underbrace{(v_t(n)+\widehat{q}_t(n,l))}_{\text{predicted log supply}}. \tag{44}$$

The instrument is the difference between the predicted log demand, excluding investor i's demand, and the predicted log supply. The predicted log demand depends on the size distribution of investor countries, captured by their outside wealth, and the bilateral distance between investor and issuer countries. The predicted log demand for issuer n is high if there are large investor countries in close proximity.

Figure 4 explains the intuition for the instrument. The vertical axis is the predicted log demand, excluding the US investors' demand. The horizontal axis is the predicted log supply. Thus, the instrument for estimating the US investors' demand is the value of the vertical axis minus the value of the horizontal axis. In Panel B for long-term debt, the Netherlands (NLD) and Australia (AUS) have similar values for the predicted log supply since they are similar in size as measured by a weighted average of GDP and population. However, the predicted log demand is much higher for Dutch long-term debt than for Australian long-term debt. The gravity effect favors the Netherlands over Australia because it neighbors large investor countries in Europe. Thus, US investors face lower expected returns on Dutch long-term debt, through a higher long-term debt price and/or a higher real exchange rate. Generalizing this example, smaller issuer countries that are in close proximity to larger investor countries have a higher exogenous component of asset demand and consequently higher asset prices and/or real exchange rates.

To explain the functional form for the instrument (44), we go back to market clearing (40). Suppose that we take logarithms, delete investor i's demand, substitute wealth $A_{j,t}$ with equation (30), replace the portfolio weights $w_{j,t}(n,l)$ with the predicted portfolio weights $\widehat{w}_j(n,l)$, and replace log supply with the predicted log supply. Then equation (40) becomes $p_t(n,l) + e_t(n) - v_t(n) = \mathrm{IV}_{i,t}(n,l)$. Thus, the instrument is the sum of log asset price and log real exchange rate in a counterfactual market, in which market clearing depends on the relative size of countries and the bilateral distance between them. The instrument is indexed by i because we isolate exogenous variation in the residual supply, by excluding investor i's demand.

Threats to Identification

Our identification strategy relies on the functional form of asset demand (39). The coefficient on the expected return determines how investors substitute in response to cross-sectional as well as time-series variation in asset prices. Therefore, the estimated elasticities based on cross-sectional variation may not have external validity for predicting substitution in response to time-series variation in asset prices. The literature on asset demand estimation, especially across countries and asset class, is still at an early stage. We hope to learn the external validity of our estimates as better data and identification strategies become available.

The coefficient on the expected return is the same for both domestic and foreign assets. Koijen et al. (2021) use euro-area government debt holdings by investor type and find that foreign investors have higher demand elasticities than euro-area investors. In principle, we could interact the expected return with an indicator variable for domestic ownership in asset demand (39). However, the instrument (44) generates primarily variation across issuer countries and little variation across investor countries. Thus, we identify the coefficient on the expected return primarily from foreign portfolio holdings, which could lead to a biased estimate of the aggregate demand elasticity. Future research could use better data or a different identification strategy to identify heterogeneous demand elasticities between domestic and foreign assets.

Estimated Demand

Table 4 reports the estimated coefficients for demand within asset class. The estimated coefficient on the expected return is 14.33 for short-term debt, 4.52 for long-term debt, and 10.33 for equity. This coefficient implies that the portfolio weight within equity increases by 10.33 percent per one percentage point increase in the expected return.

The coefficients on the macro variables have consistent signs across asset classes. The estimated coefficients on log GDP and log GDP per capita are positive, which implies that asset demand increases in the issuer country's size and wealth. Asset demand decreases in inflation. The estimated coefficient on inflation is −9.22 for long-term debt, which implies that the portfolio weight decreases by 9.22 percent per one percentage point increase in inflation. The estimated coefficient on equity volatility is −5.89 for equity, which implies that the portfolio weight decreases by 5.89 percent per one percentage point increase in equity volatility. The estimated coefficient on the sovereign debt rating is 10.24 for long-term debt, which implies that the portfolio weight increases by 10.24 percent per one percentage point decrease in the ten-year default rate.

The bilateral distance is a highly significant determinant of asset demand. The estimated coefficient on the bilateral distance is −0.08 for short-term debt, −0.18 for long-term debt, and −0.15 for equity. This coefficient implies that the portfolio weight within equity decreases by 15 percent per 1,000 km increase in the bilateral distance. A leading hypothesis for this gravity effect is that informational frictions between countries increase in the bilateral distance (Portes et al. 2001; Portes and Rey 2005).

Home bias is a prominent feature of asset demand. The estimated coefficient on the indicator variable for domestic ownership is 8.46 for short-term debt, 6.19 for long-term debt, and 7.69 for equity. This coefficient implies that the portfolio weight within equity increases by a factor of nearly nine when domestically owned.

We test for weak instruments in Table 4. For all asset classes, the first-stage F-statistic is well above the critical value of 16.38 for a test of weak instruments at the 5 percent significance level (Stock and Yogo 2005).

Robustness

In the predictive regression for equity in Table 3, the estimated coefficient on log market-to-book equity is -0.15 with a standard error of 0.22. A longer time series is necessary to estimate this coefficient more precisely because mean reversion in market-to-book equity operates at a low frequency. When we use the data on the S&P 500 from 1946 to 2020 to estimate a predictive regression of equity returns on log market-to-book equity, the estimated coefficient is -0.09 with a t-statistic of -1.90. We then repeat the asset demand estimation, imposing this coefficient on log market-to-book equity to construct expected equity returns. In Table D1 of Appendix D, the estimated demand coefficients hardly change, which implies that the asset demand estimation is not sensitive to sampling error in the predictive regression.

C. *Demand across Asset Classes*

Estimating Equations

Dividing equation (34) for short- or long-term debt (i.e., $l = S, L$) by the same equation for equity (i.e., $l = E$) and taking logarithms, we have

$$\begin{aligned}(45)\qquad \log\left(\frac{w_{i,t}(l)}{w_{i,t}(E)}\right) =& \rho_l \log\left(1+\sum_{m=0}^{N}\delta_{i,t}(m,l)\right) - \rho_E \log\left(1+\sum_{m=0}^{N}\delta_{i,t}(m,E)\right) \\ &+ \alpha_l + \xi_{i,t}(l) \\ =& -\rho_l \log(w_{i,t}(0|l)) + \rho_E \log(w_{i,t}(0|E)) + \alpha_l + \xi_{i,t}(l).\end{aligned}$$

The second line follows from equation (33), which relates the inclusive value to the outside portfolio weight. Equation (45) says that the demand for long-term debt relative to equity depends on their relative inclusive value. An investor substitutes from long-term debt to equity if the characteristics of equity become relatively more attractive (e.g., lower prices).

Equation (45) is a panel regression model, where the observations are investor i's aggregate portfolio weight on asset class l relative to equity in year t. The coefficient ρ_l represents interactions with asset-class fixed effects that are equal to ρ_S for short-term debt and ρ_L for long-term debt. The intercept α_l represents asset-class fixed effects that are equal to α_S for short-term debt and α_L for long-term debt. The outside portfolio weights (i.e., $w_{i,t}(0|l)$ and $w_{i,t}(0|E)$), which depend on exchange rates and asset prices, are endogenous with asset-class latent demand $\xi_{i,t}(l)$.

Identifying Assumptions

We isolate the inelastic component of the outside portfolio weights, which do not depend directly on exchange rates and asset prices, due to home bias and local bias. Consider the example of Japan versus Germany. In Table 1, Japanese investors own 96 percent of domestic long-term debt, whereas German investors own only 58 percent of domestic long-term debt. For Japanese investors, the stronger home bias increases the inclusive value of long-term debt and decreases the outside portfolio weight on long-term debt. The counterfactual prediction is that if Japanese investors had weaker home bias like German investors, the outside portfolio weight on long-term debt would increase, and the aggregate portfolio weight on long-term debt would decrease. Thus, the varying strength of home bias and local bias across investors identifies the asset-class demand elasticities in equation (45).

Let $D_i(n)$ be the bilateral distance between investor i and issuer n. Let $\mathbb{1}_i(n)$ be an indicator function that is equal to one if investor i and issuer n are the same country. For each investor i and asset class l, we estimate a regression:

$$\log\left(\frac{w_{i,t}(n|l)}{w_{i,t}(0|l)}\right) = \boldsymbol{\Upsilon}'_{i,l}\begin{bmatrix} D_i(n) \\ \mathbb{1}_i(n) \end{bmatrix} + \upsilon_{i,l} + \eta_{i,t}(n,l). \tag{46}$$

Let

$$\widehat{\delta}_i(n,l) = \exp\left(\widehat{\boldsymbol{\Upsilon}}'_{i,l}\begin{bmatrix} D_i(n) \\ \mathbb{1}_i(n) \end{bmatrix} + \widehat{\upsilon}_{i,l}\right), \tag{47}$$

where $\widehat{\boldsymbol{\Upsilon}}_{i,l}$ and $\widehat{\upsilon}_{i,l}$ represent the corresponding estimated coefficients.

We construct investor i's predicted outside portfolio weight on asset class l in year t as

$$\widehat{w}_i(0|l) = \frac{1}{1 + \sum_{m=0}^{N} \widehat{\delta}_i(m,l)}. \tag{48}$$

The predicted outside portfolio weight is lower for investors with stronger home bias or local bias. We estimate regression (45) by instrumental variables, where the three instruments are $-\log(\widehat{w}_i(0|S))$, $-\log(\widehat{w}_i(0|L))$, and $\log(\widehat{w}_i(0|E))$.

Estimated Demand

Table 5 reports the estimated coefficients for demand across asset classes. The coefficient on log outside portfolio weight is $\rho_S = 0.25$ for short-term debt, $\rho_L = 0.53$ for long-term debt, and $\rho_E = 0.49$ for equity. For all asset classes, we reject the null hypothesis that the coefficient is zero. Thus, substitution across asset classes is important for exchange rates and asset prices.

D. Demand Elasticities

Differentiating market clearing (37) with respect to $q_t(n,l)$, we have

$$1 - \frac{\partial \log\left(\sum_{i=1}^{I} A_{i,t} w_{i,t}(n,l)\right)}{\partial p_t(n,l)} = -\left(\frac{\partial p_t(n,l)}{\partial q_t(n,l)}\right)^{-1}. \tag{49}$$

The aggregate demand elasticity with respect to price is minus the inverse of the price impact of a supply shock. Based on the estimated demand system, we compute the aggregate demand elasticities, as we describe in Appendix C, and average them across years and issuer countries for each asset class. We compute the standard error for the mean demand elasticity by the delta method. The mean demand elasticities are 25.2 (1.9) for short-term debt, 3.1 (0.4) for long-term debt, and 1.2 (1.0) for equity with the standard errors in parentheses.

Accounting for differences in the level of aggregation, identification strategies, and sampling error, our demand elasticities are broadly consistent with the estimates for euro-area government debt (Koijen et al. 2021), US corporate bonds (Bretscher et al. 2023; Chaudhary et al. 2023), and US stocks (Chang et al. 2014; Koijen and Yogo 2019; Pavlova and Sikorskaya 2022). These papers use more granular portfolio holdings data on institutions and households but focus on a narrower set of countries and asset classes, ruling out potentially important substitution effects. We use portfolio holdings at the country level, which could hide heterogeneity in the demand elasticities across investors within a country. However, we allow for the full range of substitution effects across countries and asset classes, conditional on year fixed effects by asset class.

E. Model of Short-Term Rates

Table 6 reports the estimated coefficients for the model of short-term rates (18). We include country fixed effects to model persistent differences in short-term rates across countries and to identify the coefficients from the time-series variation in the macro variables. Inflation is the most important variable with an estimated coefficient of -0.11. This estimate implies that the short-term debt price decreases by 11 basis points per one percentage point increase in inflation. Equivalently, the short-term rate increases by 44 basis points because its maturity is three months (i.e., 0.25 years).

V. Variation in Exchange Rates and Asset Prices

Based on the estimated demand system and market clearing, we decompose the annual variation in exchange rates and asset prices into portfolio flows and shifts in asset demand through macro variables and latent demand. We also present a case study of the European sovereign debt crisis.

A. Variance Decomposition of Exchange Rates and Asset Prices

As we described in Section II, the estimated demand system and market clearing define an implicit function (38) for exchange rates and asset prices. Exchange rates and asset prices can change from one year to the next only if one of the variables of the implicit function changes. We develop a variance decomposition that attributes every movement in exchange rates and asset prices to changes in three groups of variables.

First, as we describe in Appendix C, we change the wealth distribution through portfolio flows in year $t+1$. Because world assets must equal world liabilities, we also change the asset quantities from $\boldsymbol{Q}_t$ to $\boldsymbol{Q}_{t+1}$. We then compute the counterfactual exchange rates and asset prices that clear all markets. We denote the counterfactual exchanges rates as $\boldsymbol{e}(\boldsymbol{Q}_{t+1})$. Second, we change the macro variables from $\boldsymbol{X}_t$ to $\boldsymbol{X}_{t+1}$, which shift asset demand and update the short-term rates. We denote the counterfactual exchanges rates as $\boldsymbol{e}(\boldsymbol{X}_{t+1})$. Third, we change latent demand for the portfolio weights within asset class, the aggregate portfolio weights across asset classes, and the model of short-term rates. We also change the outside wealth from $\boldsymbol{O}_t$ to $\boldsymbol{O}_{t+1}$. We further break up this step into latent demand and outside wealth by investor group. Since we have now changed all variables from their values in year t to $t+1$, the counterfactual exchange rates and asset prices are equal to the realized exchange rates and asset prices (i.e., $\boldsymbol{e}_{t+1}$ and $\boldsymbol{p}_{t+1}$). In each step, the wealth distribution updates endogenously, through the intertemporal budget constraint, as exchange rates and asset prices change.

Thus, the realized exchange rate growth from year t to $t+1$ is the sum of the changes across these counterfactual experiments:

$$\boldsymbol{e}_{t+1} - \boldsymbol{e}_t = (\boldsymbol{e}(\boldsymbol{Q}_{t+1}) - \boldsymbol{e}_t) + (\boldsymbol{e}(\boldsymbol{X}_{t+1}) - \boldsymbol{e}(\boldsymbol{Q}_{t+1})) + (\boldsymbol{e}_{t+1} - \boldsymbol{e}(\boldsymbol{X}_{t+1})). \tag{50}$$

This equation implies a variance decomposition of exchange rate growth:

$$\begin{aligned} 1 = & \frac{\operatorname{Cov}(\boldsymbol{e}(\boldsymbol{Q}_{t+1}) - \boldsymbol{e}_t, \boldsymbol{e}_{t+1} - \boldsymbol{e}_t)}{\operatorname{Var}(\boldsymbol{e}_{t+1} - \boldsymbol{e}_t)} + \frac{\operatorname{Cov}(\boldsymbol{e}(\boldsymbol{X}_{t+1}) - \boldsymbol{e}(\boldsymbol{Q}_{t+1}), \boldsymbol{e}_{t+1} - \boldsymbol{e}_t)}{\operatorname{Var}(\boldsymbol{e}_{t+1} - \boldsymbol{e}_t)} \\ & + \frac{\operatorname{Cov}(\boldsymbol{e}_{t+1} - \boldsymbol{e}(\boldsymbol{X}_{t+1}), \boldsymbol{e}_{t+1} - \boldsymbol{e}_t)}{\operatorname{Var}(\boldsymbol{e}_{t+1} - \boldsymbol{e}_t)}. \end{aligned} \tag{51}$$

We analogously define the variance decompositions of short-term rates, long-term yields, and log market-to-book equity.

The variance decomposition is an accounting exercise, based on an econometric model of asset demand and market clearing. It is in the same spirit as a variance decomposition of stock returns, based on a present-value identity and an econometric model of stock price and dividend dynamics (Campbell 1991). We cannot interpret our variance decomposition or Campbell (1991) as causal effects that would arise from a fully specified macro model. Nevertheless, these variance decompositions are useful for identifying important sources of variation and for generating empirical moments to test existing macro models and to help design future models.

B. Estimated Variation Decomposition

Table 7 reports the variance decomposition of exchange rates, weighted by the relative size of the short-term debt market. The weighting is equivalent to constructing a value-weighted portfolio of exchange rates relative to the US dollar. Portfolio flows explain a statistically insignificant 1 percent of the variation in exchange rates. The macro variables explain 16 percent of the variation in exchange rates with a standard error of 6 percent. Latent demand explains the remaining 83 percent of the variation in exchange rates with a standard error of 7 percent. When we further decompose latent demand by investor group, foreign exchange reserves explain 10 percent, North American investors explain 32 percent, European investors explain 22 percent, and Pacific investors explain 22 percent. These investor groups naturally represent the largest investors in Table 2.

Table 7 also reports the variance decomposition of short-term rates, weighted by the relative size of the short-term debt market. The macro variables explain 14 percent of the variation in short-term rates with a standard error of 6 percent, primarily due to the importance of inflation in the model of short-term rates (see Table 6). Latent demand explains the remaining 86 percent of the variation in short-term rates with a standard error of 6 percent.

Table 7 also reports the variance decomposition of long-term yields, weighted by the relative size of the long-term debt market. Portfolio flows explain 58 percent of the variation in long-term yields with a standard error of 19 percent. The macro variables explain an additional 41 percent of the variation in long-term yields with a standard error of 9 percent. Latent demand explains a statistically insignificant 1 percent of the variation in long-term yields with offsetting effects across investor groups.

Table 7 also reports the variance decomposition of log market-to-book equity, weighted by the relative size of the equity market. Portfolio flows explain 20 percent of the variation in log market-to-book equity with a standard error of 7 percent. The macro variables explain an additional 19 percent of the variation in log market-to-book equity with a standard error of 3 percent. Latent demand explains the remaining 61 percent of the variation in log market-to-book equity with a standard error of 7 percent. When we further decompose latent demand by investor group, North American investors explain 15 percent, European investors explain 26 percent, Pacific investors explain 9 percent, and emerging market investors explain 12 percent.

C. Relation to the Exchange Rate Disconnect

In Table D2 of Appendix D, we estimate reduced-form regressions of annual changes in exchange rates and asset prices on contemporaneous changes in the macro variables. These regressions establish a baseline level of explanatory power for the macro variables. In particular, we find an R^2 of 8 percent for exchange rates. In Table 7, we find higher explanatory power for exchange rates, based on the estimated demand system. We relate this finding to the literature on the exchange rate disconnect (Meese and Rogoff 1983).

First, our results are consistent with the recent literature (Engel and Wu 2018; Camanho et al. 2022; Lilley et al. 2022). These papers find higher explanatory power after the global financial crisis, based on variables that capture portfolio flows or the special demand for US assets. That is, the exchange rate disconnect is less puzzling in more recent sample periods and with variables that relate to asset demand. In Table D7 of Appendix D, we report the variance decomposition of exchange rates for the subsample from 2012 to 2020. We find that portfolio flows explain 21 percent of the variation in exchange rates with a standard error of 5 percent. The macro variables explain an additional 21 percent of the variation in exchange rates with a standard error of 8 percent.

Second, we perform an out-of-sample test in the spirit of Meese and Rogoff (1983). In Appendix D, we estimate the asset demand system on the subsample from 2003 to 2011. We report the estimated coefficients for demand within asset class in Table D4, demand across asset classes in Table D5, and the model of short-term rates in Table D6. Based on the estimated demand system, we predict exchange rates and asset prices out of sample from 2012 to 2020. In Table D7, we compare the variance decomposition of exchange rates and asset prices, based on in-sample and out-of-sample estimates of the asset demand system. The standard errors are large due to the short sample period, making the exercise less informative than we had hoped. However, we continue to find that portfolio flows have explanatory power for exchange rates.

D. A Case Study of the European Sovereign Debt Crisis

By focusing on particular countries and asset classes, we can use the same variance decomposition to interpret major economic events. We illustrate this application through the European sovereign debt crisis, which caused the most extreme asset price movements in our sample. This case study clearly illustrates the separate roles that the macro variables and latent demand play in the asset demand system.

Table 8 reports the variance decomposition of long-term yields in Greece, Italy, and Portugal. In Greece, the macro variables are relatively more important than latent demand. The macro variables explain 47 percent, and latent demand explains 31 percent of the variation in the Greek long-term yield. In Italy and Portugal, latent demand is relatively more important than the macro variables. Latent demand explains 112 percent of the variation in the Italian long-term yield and 73 percent of the variation in the Portuguese long-term yield. When we further decompose latent demand by investor group, European investors alone explain 96 percent of the variation in the Italian long-term yield and 64 percent of the variation in the Portuguese long-term yield.

Figure 5 is a visual representation of the variance decomposition in Table 8. It shows the time series of the annual changes in the long-term yields and their decomposition into changes due to the macro variables and latent demand. A sharp increase at the onset of the European sovereign debt crisis in 2011 is followed by a sharp decrease when the European Central Bank intervened in 2012. On the one hand, Greece had a realized solvency problem in 2011. The sharp change in the macro variables, particularly a spike in equity volatility and a rating downgrade, explains the sharp increase in the Greek long-term yield. On the other hand, Italy and Portugal had not experienced the same extreme movements in the macro variables in 2011, but investors viewed these countries as vulnerable. Latent demand, which captures perceived rather than realized risk, explains the sharp changes in the Italian and Portuguese long-term yields. In particular, latent demand captures the calming impact of the Mario Draghi speech in 2012.

VI. Convenience Yield on US Assets

US assets enjoy a special status because the US dollar is the global reserve currency and US Treasury debt is the global safe asset (Gourinchas and Rey 2007; Jiang et al. 2021). In Table 4, the specification for demand within asset class includes expected returns and measures of risk and asset market size. Thus, the observed characteristics already capture the high foreign demand for US assets because of their low risk and large market size. Nevertheless, foreign investors could have special demand for US assets beyond the observed characteristics that is part of latent demand. We examine the evidence for the special demand for US assets and its implications for asset prices.

A. Special Demand for US Assets

Table 9 reports the cross-sectional mean of the foreign investors' latent demand for US assets by year and asset class. We exclude the US investors' latent demand because it is difficult to distinguish from heterogeneous home bias across investors and over time. Latent demand includes the year fixed effects from the asset demand estimation to account for common time-series variation in latent demand. The mean latent demand for US assets is uniformly positive across years and asset classes. The overall mean is 1.1 for short-term debt, 0.8 for long-term debt, and 1.0 for equity. This estimate implies that the foreign demand for US equity is 100 percent higher than the average demand for foreign equity, controlling for the observed characteristics.

As a point of comparison, Table 9 reports the cross-sectional mean of the foreign investors' latent demand for euro-area assets by year and asset class. We exclude the euro-area investors' latent demand. The overall mean by asset class is comparable to that for US assets. However, the mean latent demand for euro-area assets is not uniformly positive across years and asset classes. Overall, US assets appear to be more special than euro-area assets.

B. Estimated Convenience Yield

Although there are various definitions of the convenience yield in the literature, we choose a definition that is most natural in our context. The convenience yield is the counterfactual change in US asset prices in the absence of special demand for US assets. Starting with the estimated demand system, we subtract the values in Table 9 from the foreign investors' latent demand by year and asset class. This step recenters the latent demand for US assets to make the United States look like an average country. We then compute the counterfactual asset prices through market clearing. We further decompose the total change in asset prices into the sum of changes by investor group, by sequentially recentering the latent demand by investor group and computing the counterfactual asset prices.

In the absence of special demand for US short-term debt, the US dollar is weaker and expected to appreciate at a higher rate. Thus, a portfolio of foreign short-term debt earns a lower expected return in US dollars. In Table 10, a value-weighted exchange rate in US dollars per local currency unit is 5.36 percent higher. Consequently, the expected annual return on a value-weighted portfolio of foreign short-term debt is 1.45 percent lower. We interpret this estimate as a convenience yield of 1.45 percent on the US dollar. We decompose this convenience yield by investor group and find that the most important sources are 0.94 percent from foreign exchange reserves, 0.24 percent from European investors, and 0.14 percent from Pacific investors.

In the absence of special demand for US long-term debt, its yield and expected return are higher. In Table 10, the long-term yield is 0.76 percent higher, and the expected annual return is 2.81 percent higher. We decompose this convenience yield by investor group and find that the most important sources are 1.02 percent from foreign exchange reserves, 0.85

percent from European investors, and 0.78 percent from Pacific investors. Figure 6 shows the time series of the US long-term yield and its convenience yield. The convenience yield appears to have decreased slightly in the low interest rate environment.

In the absence of special demand for US equity, its market-to-book equity is lower, and its expected return is higher. In Table 10, market-to-book equity is 3.37 percent lower, and the expected annual return is 0.50 percent higher. We decompose this convenience yield by investor group and find that the most important sources are 0.26 percent from European investors and 0.13 percent from Pacific investors.

VII. Conclusion

We derive an asset demand system from a traditional model of consumption and portfolio choice under heterogeneous beliefs, designed to match international portfolio holdings together with exchange rates and asset prices across all countries. Based on the estimated demand system and market clearing, we decompose the annual variation in exchange rates and asset prices into portfolio flows and shifts in asset demand through macro variables and latent demand. Portfolio flows explain 58 percent of the variation in long-term yields and 20 percent of the variation in log market-to-book equity. The macro variables explain 16 percent of the variation in exchange rates, 14 percent of the variation in short-term rates, 41 percent of the variation in long-term yields, and 19 percent of the variation in log market-to-book equity. We also estimate the convenience yield on US assets. In units of expected annual returns, the mean convenience yield is 1.45 percent on the US dollar, 2.81 percent on US long-term debt, and 0.50 percent on US equity.

Recent work on international macro models emphasizes the importance of latent demand shocks (i.e., asset demand shocks unrelated to fundamentals) to resolve longstanding puzzles in international finance (Blanchard et al. 2005; Gabaix and Maggiori 2015; Itskhoki and Mukhin 2021). These models could match the volatility of exchange rates and asset prices with higher demand elasticities and smaller demand shocks or lower demand elasticities and larger demand shocks. We estimate demand elasticities and provide direct observations of latent demand, which are empirical targets to test existing international macro models and to help design future models. We estimate mean demand elasticities of 25.2 (1.9) for short-term debt, 3.1 (0.4) for long-term debt, and 1.2 (1.0) for equity with the standard errors in parentheses. We also find that latent demand explains 83 percent of the variation in exchange rates, 86 percent of the variation in short-term rates, 1 percent of the variation in long-term yields, and 61 percent of the variation in market-to-book equity.

Our methodology, based on the estimated demand system and market clearing, could be used for counterfactual analysis of any variables that depend on exchange rates and asset prices. Following our methodology, Jiang et al. (2022a) decompose low-frequency movements in the US net foreign asset position, which depends on the realized path of exchange rates and asset prices. Jiang et al. (2022b) decompose low-frequency movements in the US dollar. Fang et al. (2022) find that nonbank institutions have more elastic demand than private banks and central banks and consequently are important for the pricing of government debt. These papers provide additional moments to test existing international macro models and to help design future models.

Based on a vector autoregression, Clarida and Gali (1994), Eichenbaum and Evans (1995), and Inoue and Rossi (2019) find that both conventional and unconventional monetary policy affect exchange rates. Based on an event study, Gagnon et al. (2011) and Krishnamurthy and Vissing-Jørgensen (2011) find that unconventional monetary policy affects long-term yields. Fundamentally, unconventional monetary policy concerns changes in the supply of long-term debt and their impact on exchange rates and asset prices through substitution effects. By modeling this mechanism directly, the demand system approach is suited to study the simultaneous and cumulative impact of conventional and unconventional monetary policy across many countries. Future work could use the demand system approach to analyze and to predict the impact of monetary shocks on exchange rates and asset prices (Koijen et al. 2021).

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TABLE 1. MARKET VALUES OF FINANCIAL ASSETS

Issuer	Short-term debt			Long-term debt			Equity		
	Billion US$	Domestic share	Share in reserves	Billion US$	Domestic share	Share in reserves	Billion US$	Domestic share	Share in reserves
Developed markets: North America									
Canada	521	0.89	0.06	2,522	0.77	0.05	6,515	0.87	0.00
United States	5,489	0.92	0.04	41,070	0.84	0.05	55,623	0.87	0.00
Developed markets: Europe									
Austria	18	0.15	0.65	559	0.49	0.08	282	0.79	0.00
Belgium	121	0.69	0.11	1,152	0.62	0.06	1,739	0.93	0.00
Finland	69	0.60	0.16	384	0.43	0.09	678	0.78	0.00
France	628	0.79	0.12	5,065	0.65	0.07	10,614	0.89	0.00
Germany	321	0.43	0.34	4,342	0.58	0.13	3,672	0.57	0.00
Italy	168	0.62	0.01	3,749	0.78	0.00	2,384	0.89	0.00
Netherlands	67	0.40	0.25	1,235	0.45	0.08	6,057	0.80	0.00
Portugal	26	0.60	0.01	336	0.69	0.00	386	0.92	0.00
Spain	195	0.65	0.12	2,621	0.66	0.04	2,229	0.88	0.00
Denmark	48	0.58	0.29	670	0.75	0.02	1,705	0.85	0.00
Israel	29	0.90	0.01	509	0.90	0.00	660	0.86	0.00
Norway	30	0.60	0.08	224	0.19	0.11	1,038	0.91	0.00
Sweden	123	0.55	0.07	428	0.46	0.05	3,019	0.88	0.00
Switzerland	115	0.76	0.16	908	0.88	0.03	3,747	0.75	0.00
United Kingdom	341	0.84	0.04	4,163	0.84	0.04	6,666	0.76	0.00
Developed markets: Pacific									
Australia	202	0.89	0.04	1,824	0.71	0.04	1,763	0.73	0.00
Hong Kong	13	0.40	0.06	55	0.11	0.02	2,454	0.81	0.00
Japan	1,889	0.74	0.12	13,467	0.96	0.01	12,172	0.87	0.00
New Zealand	9	0.71	0.10	125	0.76	0.02	1,030	0.96	0.00
Singapore	41	0.04	0.39	225	0.66	0.03	887	0.82	0.00
Emerging markets									
Greece	16	0.71	0.00	134	0.86	0.01	182	0.91	0.00
Brazil	399	0.98	0.00	1,434	0.90	0.00	2,399	0.91	0.00
China	455	0.80	0.01	17,359	0.97	0.00	15,002	0.77	0.00
Colombia	27	0.99	0.00	185	0.81	0.00	483	0.99	0.00
Czech Republic	28	0.00	0.00	95	0.54	0.00	106	0.98	0.00
Hungary	7	0.99	0.00	107	0.79	0.00	104	0.89	0.00
India	326	0.98	0.00	2,027	0.97	0.00	2,354	0.80	0.00
Malaysia	18	0.83	0.01	342	0.84	0.00	447	0.89	0.00
Mexico	94	0.96	0.00	591	0.78	0.00	1,313	0.94	0.00
Philippines	17	0.99	0.00	94	0.78	0.00	261	0.88	0.00
Poland	42	0.99	0.00	301	0.77	0.00	255	0.91	0.00
Russia	9	0.42	0.10	298	0.69	0.01	3,039	0.96	0.00
South Africa	45	0.98	0.01	196	0.75	0.01	1,105	0.91	0.00
South Korea	309	0.92	0.03	2,103	0.92	0.02	3,147	0.85	0.00
Thailand	75	0.98	0.00	338	0.92	0.00	538	0.86	0.00

This table reports only local currency debt. All market values are in billion US dollars at year-end 2020.

Table 2. Top Ten Investors by Asset Class

Short-term debt		Long-term debt		Equity	
Investor	Billion US$	Investor	Billion US$	Investor	Billion US$
United States	5,423	United States	38,283	United States	56,324
Japan	1,444	China	17,331	Japan	12,424
Reserves	1,025	Japan	16,206	China	11,952
France	827	United Kingdom	5,752	France	10,376
United Kingdom	496	Germany	5,513	Canada	7,361
Canada	471	France	5,490	United Kingdom	6,800
China	440	Reserves	4,952	Netherlands	5,971
Brazil	395	Italy	3,721	Germany	3,393
India	325	Canada	2,979	Switzerland	3,390
South Korea	301	South Korea	2,350	Hong Kong	3,240

The International Monetary Fund (2003–2020a) aggregates foreign exchange reserves across all foreign central banks for confidentiality. All market values are in billion US dollars at year-end 2020.

Table 3. Predictive Regressions

Variable	Exchange rate	Long-term debt	Equity
Log asset price		-0.74	-0.15
		(0.11)	(0.22)
Log real exchange rate	-0.27	-0.36	-0.54
	(0.07)	(0.07)	(0.28)
Constant		-0.07	0.25
		(0.02)	(0.20)
R^2	0.17	0.32	0.12
Observations	424	640	640

Log asset price is minus maturity times log yield for long-term debt and log market-to-book for equity. All models include country fixed effects. Robust standard errors clustered by year are reported in parentheses. The annual sample period is 2003 to 2020.

Table 4. Estimated Demand within Asset Class

Variable	Short-term debt	Long-term debt	Equity
Expected return	14.33	4.52	10.33
	(2.32)	(0.51)	(0.79)
Log GDP	1.28	1.10	1.32
	(0.02)	(0.01)	(0.02)
Log GDP per capita	3.67	2.16	3.68
	(0.35)	(0.11)	(0.19)
Inflation	-23.49	-9.22	-16.56
	(4.22)	(1.79)	(1.88)
Volatility	-2.83	-0.52	-5.89
	(0.40)	(0.27)	(0.36)
Rating	-0.77	10.24	13.96
	(1.26)	(1.29)	(1.23)
Distance	-0.08	-0.18	-0.15
	(0.01)	(0.00)	(0.01)
Indicator variables:			
Domestic ownership	8.46	6.19	7.69
	(0.18)	(0.09)	(0.14)
Reserves	0.01	0.10	-2.83
	(0.19)	(0.10)	(0.14)
Other countries	0.78	0.77	-1.86
	(0.17)	(0.06)	(0.10)
Constant	-52.35	-34.78	-50.94
	(3.67)	(1.15)	(2.14)
F-statistic for weak IV	130	1,297	521
Observations	20,549	23,431	23,779

Expected returns are the predicted values from the predictive regressions in Table 3. The sovereign debt rating is a continuous measure equal to -1 times the ten-year default rate. All models include year fixed effects. Heteroskedasticity-robust standard errors are reported in parentheses. The critical value for a test of weak instruments at the 5 percent significance level is 16.38 (Stock and Yogo 2005). The annual sample period is 2003 to 2020.

Table 5. Estimated Demand across Asset Classes

Variable	Symbol	Estimate
Log outside portfolio weight:		
Short-term debt	ρ_S	0.25
		(0.03)
Long-term debt	ρ_L	0.53
		(0.05)
Equity	ρ_E	0.49
		(0.04)
Indicator variables:		
Short-term debt	α_S	-1.21
		(0.19)
Long-term debt	α_L	0.73
		(0.18)
F-statistic for weak IV		802
Observations		1,352

Heteroskedasticity-robust standard errors are reported in parentheses. The annual sample period is 2003 to 2020.

Table 6. Estimated Model of Short-Term Rates

Variable	Coefficient
Log GDP	0.01
	(0.01)
Log GDP per capita	-0.01
	(0.01)
Inflation	-0.11
	(0.01)
Volatility	0.00
	(0.01)
Rating	-0.03
	(0.03)
Constant	-0.05
	(0.03)
Observations	442

The model includes country fixed effects. Heteroskedasticity-robust standard errors are reported in parentheses. The annual sample period is 2003 to 2020.

Table 7. Variance Decomposition of Exchange Rates and Asset Prices

Change in	Exchange rate	Short-term rate	Long-term yield	Market-to-book equity
Portfolio flows	0.01		0.58	0.20
	(0.05)		(0.19)	(0.07)
Macro variables	0.16	0.14	0.41	0.19
	(0.06)	(0.06)	(0.09)	(0.03)
Latent demand	0.83	0.86	0.01	0.61
	(0.07)	(0.06)	(0.26)	(0.07)
Reserves	0.10		0.02	-0.01
	(0.02)		(0.03)	(0.01)
North America	0.32	0.45	-0.23	0.15
	(0.09)	(0.14)	(0.20)	(0.08)
Europe	0.22	0.17	0.16	0.26
	(0.04)	(0.06)	(0.06)	(0.04)
Pacific	0.22	0.03	-0.02	0.09
	(0.06)	(0.02)	(0.02)	(0.02)
Emerging markets	-0.05	0.21	0.08	0.12
	(0.02)	(0.06)	(0.07)	(0.05)
Other countries	0.02		0.00	0.00
	(0.01)		(0.01)	(0.00)
Observations	399	416	603	603

Heteroskedasticity-robust standard errors are reported in parentheses. The observations are value-weighted by the market weights within year and asset class. The annual sample period is 2003 to 2020.

Table 8. Variance Decomposition of Long-Term Yields in the Euro Area

Change in	Greece	Italy	Portugal
Portfolio flows	0.23	0.15	0.24
	(0.11)	(0.18)	(0.05)
Macro variables	0.47	-0.27	0.02
	(0.09)	(0.17)	(0.19)
Latent demand	0.31	1.12	0.73
	(0.03)	(0.31)	(0.21)
Reserves	0.00	0.02	-0.01
	(0.01)	(0.09)	(0.03)
North America	0.01	0.08	0.05
	(0.01)	(0.07)	(0.03)
Europe	0.19	0.96	0.64
	(0.01)	(0.19)	(0.16)
Pacific	0.02	0.06	0.05
	(0.00)	(0.02)	(0.01)
Emerging markets	0.07	0.00	0.00
	(0.02)	(0.01)	(0.00)
Other countries	0.02	0.01	0.01
	(0.01)	(0.00)	(0.00)
Observations	17	17	17

Heteroskedasticity-robust standard errors are reported in parentheses. The annual sample period is 2003 to 2020.

Table 9. Mean Latent Demand

	United States			Euro area		
Year	Short-term debt	Long-term debt	Equity	Short-term debt	Long-term debt	Equity
2003	2.6	2.0	2.6	4.5	2.3	4.0
2004	1.5	1.6	1.7	4.3	2.0	3.7
2005	2.1	1.4	2.0	3.9	1.4	2.9
2006	1.3	1.4	1.3	3.3	1.4	3.0
2007	1.1	1.2	1.0	3.0	1.1	3.1
2008	1.8	1.4	1.4	4.4	1.5	3.4
2009	1.3	0.9	0.8	3.5	1.1	2.5
2010	1.5	0.8	0.7	3.0	0.9	1.7
2011	1.2	1.2	0.7	2.5	0.3	1.1
2012	0.4	0.5	-0.1	2.3	0.4	0.9
2013	0.5	0.2	0.2	1.2	0.2	0.6
2014	0.6	0.3	0.3	1.0	0.1	-0.4
2015	0.8	0.5	0.9	0.8	0.3	0.1
2016	1.0	0.6	0.8	0.4	-0.3	-0.6
2017	0.3	0.3	0.3	0.1	-0.1	-0.7
2018	0.8	0.5	1.1	0.3	-0.1	-0.8
2019	0.4	0.0	0.9	-0.3	-0.3	-1.6
2020	0.5	0.4	2.1	0.2	0.1	0.5
Mean	1.1	0.8	1.0	2.0	0.6	1.2

This table reports the cross-sectional mean of latent demand by year, issuer region, and asset class, excluding the domestic investors' latent demand. Latent demand includes the year fixed effects from the asset demand estimation. The last row reports the overall mean.

Table 10. Convenience Yields on US Assets

Investor	Foreign short-term debt		US long-term debt		US equity	
	Exchange rate	Expected return	Yield	Expected return	Market-to-book	Expected return
Total	5.36	-1.45	0.76	2.81	-3.37	0.50
	(0.58)	(0.16)	(0.10)	(0.36)	(0.40)	(0.06)
Reserves	3.49	-0.94	0.28	1.02	-0.07	0.01
	(0.44)	(0.12)	(0.03)	(0.13)	(0.01)	(0.00)
North America	0.07	-0.02	0.01	0.05	-0.37	0.05
	(0.01)	(0.00)	(0.00)	(0.00)	(0.04)	(0.01)
Europe	0.87	-0.24	0.23	0.85	-1.77	0.26
	(0.09)	(0.03)	(0.03)	(0.12)	(0.20)	(0.03)
Pacific	0.53	-0.14	0.21	0.78	-0.88	0.13
	(0.07)	(0.02)	(0.03)	(0.11)	(0.10)	(0.02)
Emerging markets	0.14	-0.04	0.01	0.05	-0.16	0.02
	(0.02)	(0.00)	(0.00)	(0.01)	(0.04)	(0.01)
Other countries	0.26	-0.07	0.01	0.05	-0.12	0.02
	(0.03)	(0.01)	(0.00)	(0.01)	(0.02)	(0.00)

This table reports the time-series mean of the counterfactual changes in exchange rates and asset prices in the absence of special demand for US assets, reported in annual percentage points. Special demand is estimated as the cross-sectional mean of latent demand for US assets by year and asset class, excluding the US investors' latent demand. Expected returns are the predicted values from the predictive regressions in Table 3. Heteroskedasticity-robust standard errors are reported in parentheses. The annual sample period is 2003 to 2020.

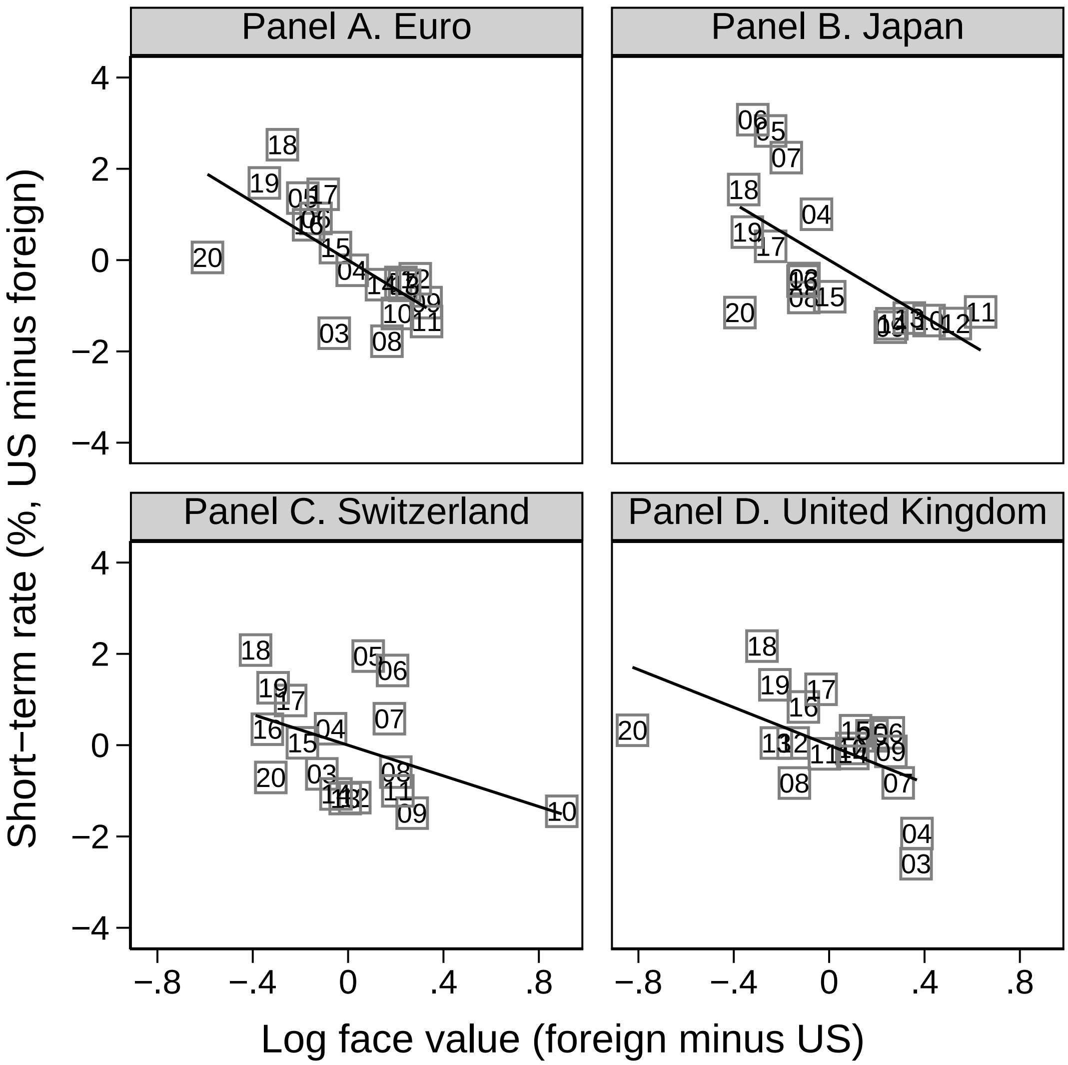

Figure 1. Relative Short-Term Debt Prices Versus Quantities

The vertical axis is the US short-term rate minus each region's short-term rate, reported in annual percentage points. The horizontal axis is each region's log face value of short-term debt in US dollars minus log face value of US short-term debt. Each axis is demeaned by the time-series mean. The two digit number represents year (e.g., 03 is 2003). Each panel shows the linear regression line.

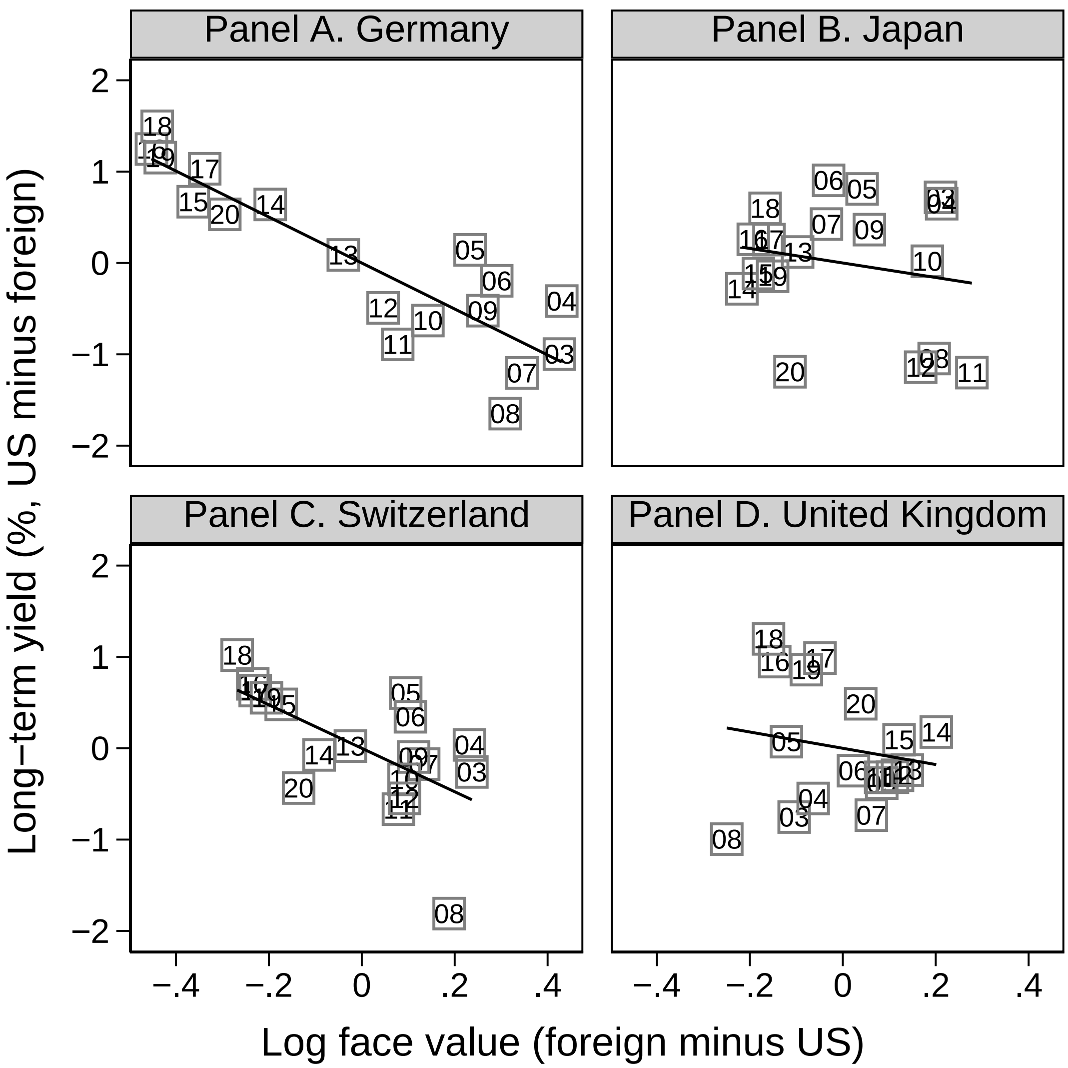

Figure 2. Relative Long-Term Debt Prices Versus Quantities

The vertical axis is the US long-term yield minus each country's long-term yield, reported in annual percentage points. The horizontal axis is each country's log face value of long-term debt in US dollars minus log face value of US long-term debt. Each axis is demeaned by the time-series mean. The two digit number represents year (e.g., 03 is 2003). Each panel shows the linear regression line.

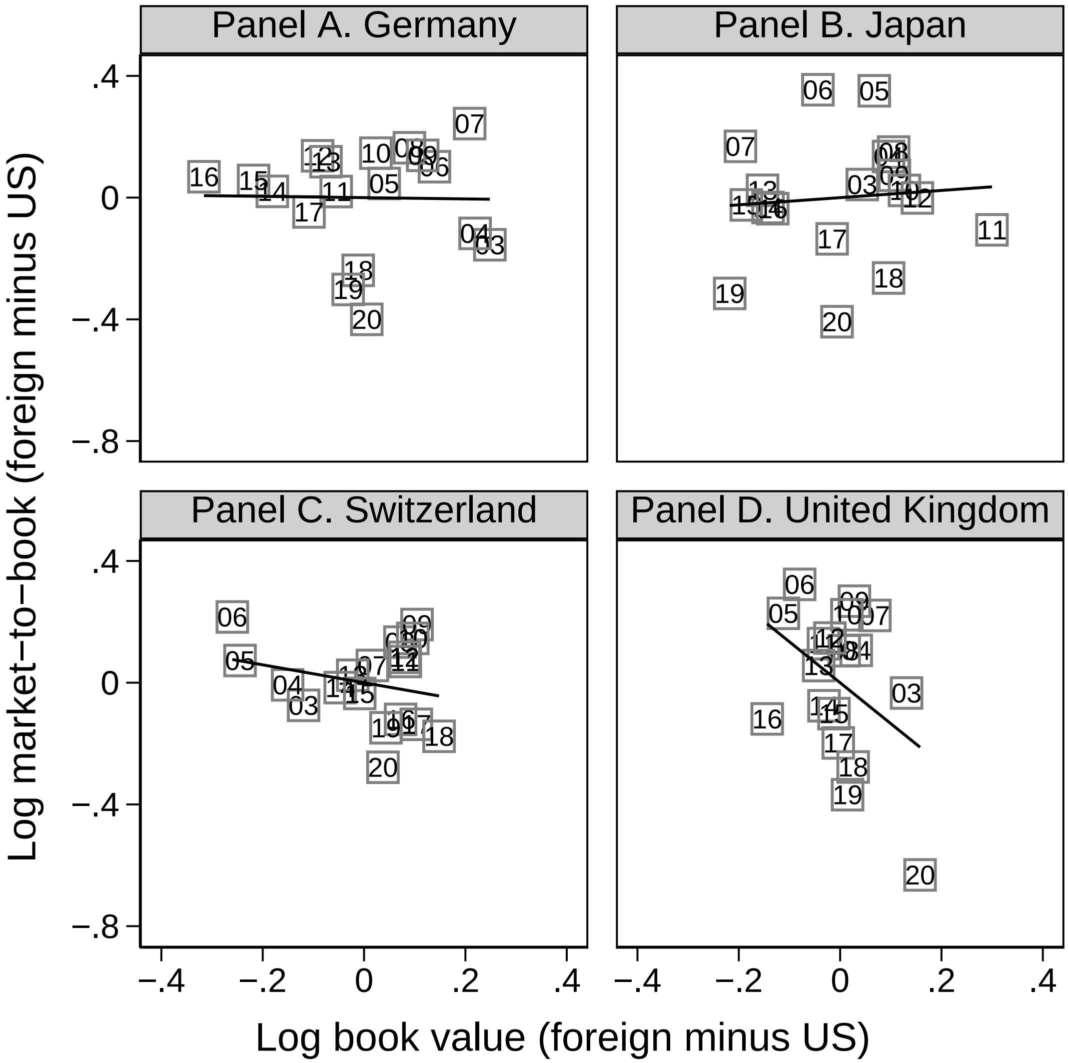

Figure 3. Relative Equity Prices Versus Quantities

The vertical axis is each country's log market-to-book equity minus the US log market-to-book equity. The horizontal axis is each country's log book equity in US dollars minus the US log book equity. Each axis is demeaned by the time-series mean. The two digit number represents year (e.g., 03 is 2003). Each panel shows the linear regression line.

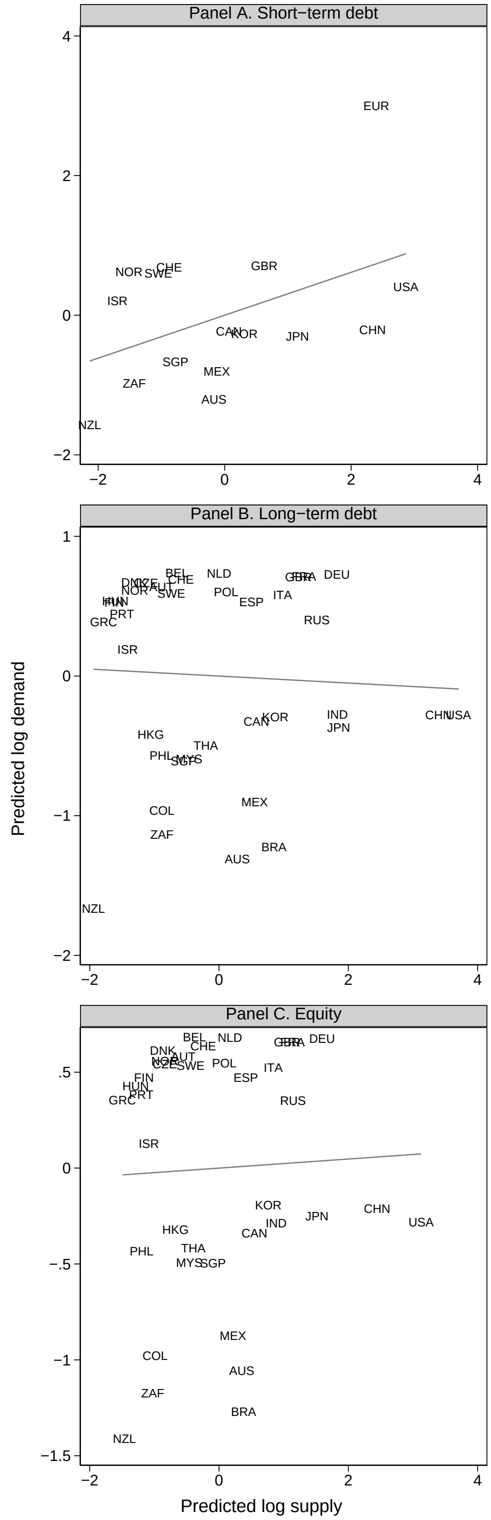

Figure 4. Instrumental Variables

Each panel reports the predicted log demand and predicted log supply from the perspective of US investors in 2020. The predicted log demand is the predicted value of a cross-sectional regression of log portfolio weights on the bilateral distance, aggregated across other investors. The predicted log supply is the predicted value of a cross-sectional regression of log asset quantity on log GDP and log population.

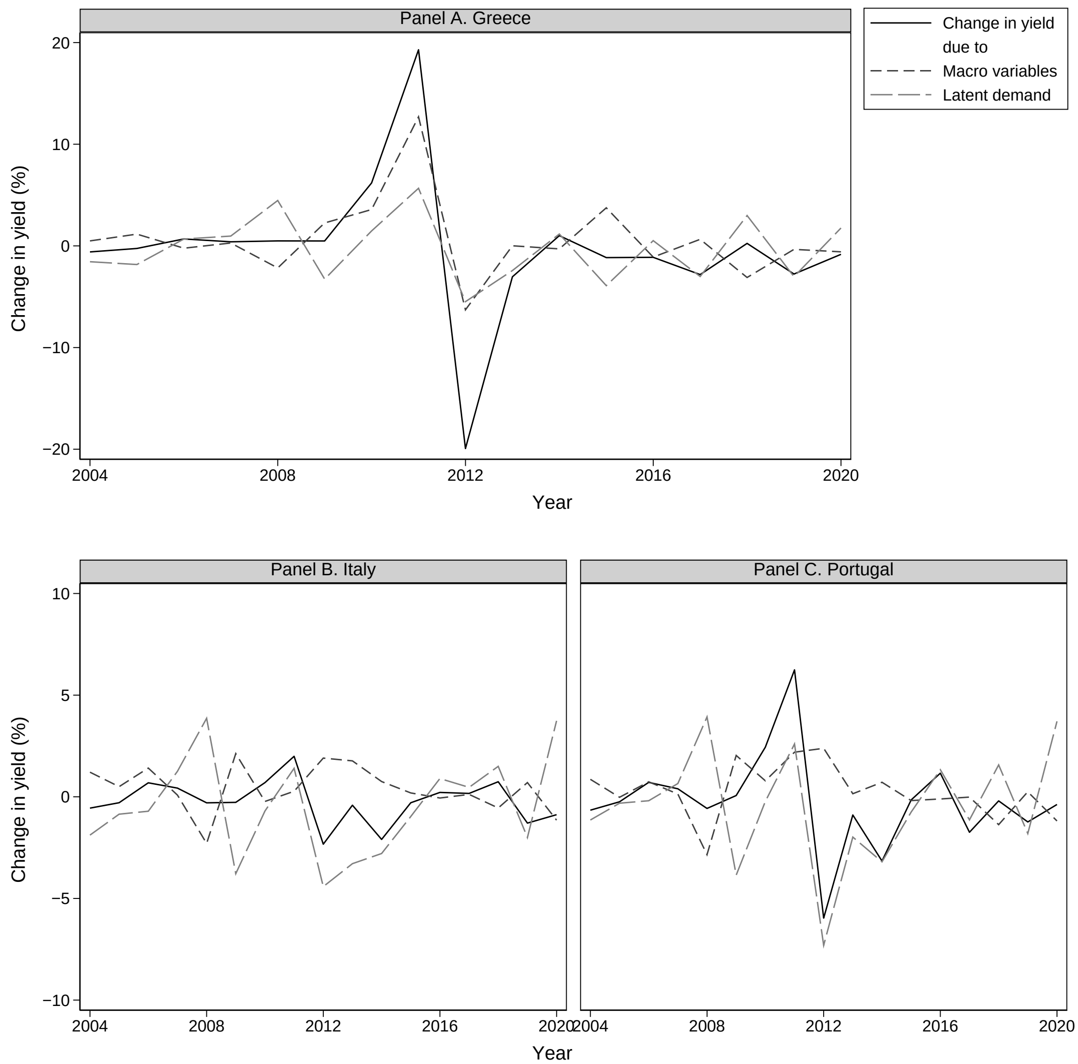

FIGURE 5. LONG-TERM YIELDS IN THE EURO AREA

Annual changes in the long-term yields are decomposed into portfolio flows and shifts in asset demand through macro variables and latent demand. This figure reports the changes due to the macro variables and latent demand only.

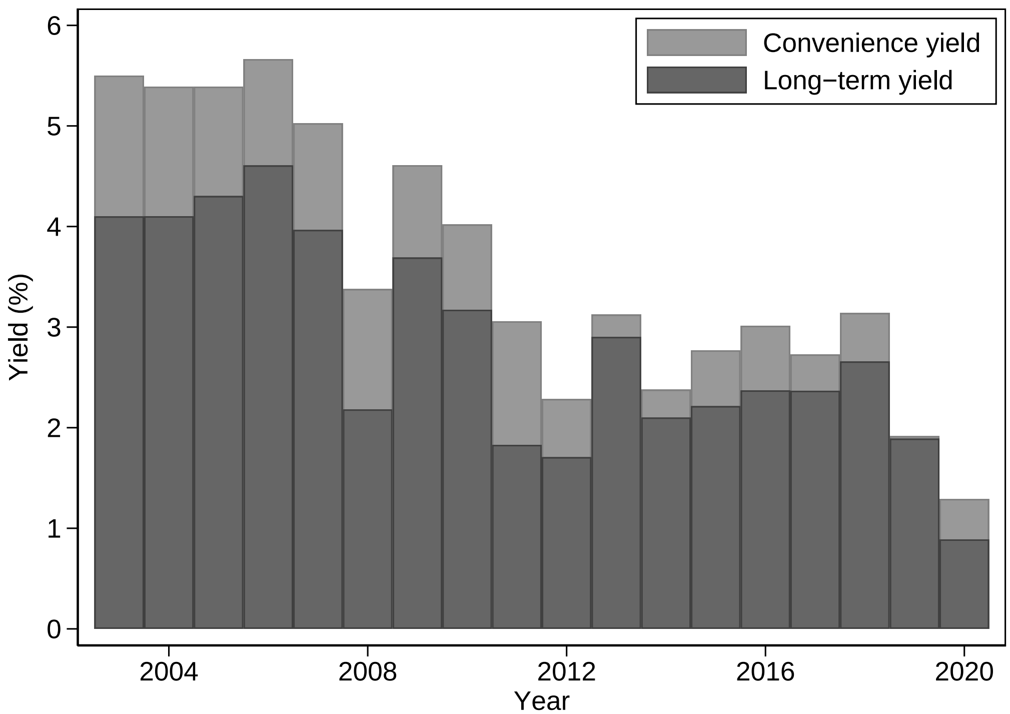

Figure 6. Convenience Yield on US Long-Term Debt

This figure reports the change in the long-term yield in the absence of special demand for US long-term debt, reported in annual percentage points. Special demand is estimated as the cross-sectional mean of latent demand for US long-term debt by year and asset class, excluding the US investors' latent demand.

Appendix A. Derivation of Characteristics-Based Asset Demand

We derive the linearized Euler equation (12) and characteristics-based asset demand from a consumption and portfolio choice model.

A. Consumption Index

Various microfoundations lead to a home bias for domestic goods, including preferences for domestic goods, trade costs, and nontradables (e.g., Obstfeld and Rogoff 2001; Itskhoki and Mukhin 2021). We are agnostic about the precise microfoundation but assume the presence of trade costs for concreteness. Each country n receives an endowment $Y_{n,t}$ of a differentiated good in local currency at time t. Investor i consumes $C_{i,t}(n)$ units of country n's good at time t, paying $B_{i,t}(n)$ per unit in its local currency. The domestic price is less than the foreign price of the same good because of trade costs (i.e., $E_t(n)B_{n,t}(n) \leq E_t(i)B_{i,t}(n)$). Market clearing for good n is $E_t(n)Y_{n,t} = \sum_{i=1}^{I} E_t(i)B_{i,t}(n)C_{i,t}(n)$.

The investor's consumption index is a constant elasticity of substitution aggregator over all goods:

$$C_{i,t} = \left(\sum_{n=1}^{N} C_{i,t}(n)^{1-1/\phi} \right)^{\frac{1}{1-1/\phi}}, \tag{A1}$$

where $\phi > 0$ is the elasticity of substitution. Utility maximization implies that the total consumption expenditure is $\sum_{i=1}^{N} B_{i,t}(n)C_{i,t}(n) = B_{i,t}C_{i,t}$, where the dual price index is

$$B_{i,t} = \left(\sum_{n=1}^{N} B_{i,t}(n)^{1-\phi} \right)^{\frac{1}{1-\phi}}. \tag{A2}$$

B. Asset Returns

Investor i can invest in short-term debt, long-term debt, or equity across N countries. Let $\boldsymbol{r}_{t+1} + \Delta\boldsymbol{e}_{t+1}$ be a $3N$-dimensional vector of log nominal returns in US dollars from time t to $t+1$, where its elements are $r_{t+1}(n,l) + \Delta e_{t+1}(n)$ for asset class l in country n. The vector of log real returns in investor i's local currency is

$$\overline{\boldsymbol{r}}_{i,t+1} = \boldsymbol{r}_{t+1} + \Delta\boldsymbol{e}_{t+1} - (\Delta e_{t+1}(i) + \Delta b_{i,t+1})\mathbf{1}, \tag{A3}$$

where $\mathbf{1}$ is a vector of ones. Other than these assets, the investor can invest in an outside asset, which has a log riskless real return $r_{i,t+1}(0)$ in investor i's local currency from time t to $t+1$.

We denote the vector of expected excess returns in investor i's local currency, relative to the outside asset, as

$$\boldsymbol{\mu}_{i,t} = \mathbb{E}_{i,t}[\overline{\boldsymbol{r}}_{i,t+1} - r_{i,t+1}(0)\mathbf{1}]. \tag{A4}$$

We denote its elements as $\mu_{i,t}(n,l)$ for asset class l in country n.

We denote the covariance matrix of log real returns in investor i's local currency as

$$\boldsymbol{\Sigma}_{i,t} = \mathbb{E}_{i,t}[(\overline{\boldsymbol{r}}_{i,t+1} - \mathbb{E}_{i,t}[\overline{\boldsymbol{r}}_{i,t+1}])(\overline{\boldsymbol{r}}_{i,t+1} - \mathbb{E}_{i,t}[\overline{\boldsymbol{r}}_{i,t+1}])']. \tag{A5}$$

We denote the diagonal elements of the covariance matrix as $\boldsymbol{\sigma}^2_{i,t}$, where its elements are $\sigma^2_{i,t}(n,l)$ for asset class l in country n. We assume that log real returns have a one-factor structure, normalizing the variance of the factor to one. Let $\boldsymbol{\Omega}_{i,t}$ be a vector of factor loadings, where its elements are $\Omega_{i,t}(n,l)$ for asset class l in country n. Let $\operatorname{diag}(\boldsymbol{\omega})$ be a diagonal matrix of idiosyncratic variances. For simplicity, we assume that the idiosyncratic variance is constant across investors and within asset class. We denote the idiosyncratic variance of asset class l as $\omega(l)$. Thus, the covariance matrix is

$$\boldsymbol{\Sigma}_{i,t} = \boldsymbol{\Omega}_{i,t}\boldsymbol{\Omega}'_{i,t} + \operatorname{diag}(\boldsymbol{\omega}). \tag{A6}$$

C. Optimal Consumption and Portfolio Choice

Investor i starts with $A_{i,t-}$ dollars of wealth at time t and receives endowment income $Y_{i,t}$ in local currency, from which it consumes $C_{i,t}$. The investor's wealth after consumption in US dollars is

$$A_{i,t} = A_{i,t-} + E_t(Y_{i,t} - B_{i,t}C_{i,t}). \tag{A7}$$

The investor allocates a share $w_{i,t}(n,l)$ of its wealth after consumption to asset class l in country n. Let $\boldsymbol{w}_{i,t}$ be a $3N$-dimensional vector of portfolio weights, where its elements are $w_{i,t}(n,l)$. The investor allocates the remaining share $1 - \boldsymbol{w}'_{i,t}\mathbf{1}$ to the outside asset. The gross real portfolio return is

$$R_{i,t+1} = \exp(r_{i,t+1}(0)) + \boldsymbol{w}'_{i,t}(\exp(\overline{\boldsymbol{r}}_{i,t+1}) - \exp(r_{i,t+1}(0)\mathbf{1})) \tag{A8}$$

in investor i's local currency from time t to $t+1$. The investor consumes its remaining wealth at time $t+1$. Thus, the intertemporal budget constraint is

$$C_{i,t+1} = R_{i,t+1}\frac{A_{i,t}}{E_t}. \tag{A9}$$

Investor i solves a consumption and portfolio choice problem at time t:

$$\max_{C_{i,t},\boldsymbol{w}_{i,t}} \frac{C_{i,t}^{1-\gamma}}{1-\gamma} + \beta\frac{\mathbb{E}_{i,t}\left[C_{i,t+1}^{1-\gamma}\right]}{1-\gamma}, \tag{A10}$$

subject to the intertemporal budget constraint (A9). The first-order conditions for consumption and portfolio choice are

$$\mathbb{E}_{i,t}\left[\beta\left(\frac{C_{i,t+1}}{C_{i,t}}\right)^{-\gamma}\exp(\overline{\boldsymbol{r}}_{i,t+1})\right] = \mathbf{1}. \tag{A11}$$

Equation (A11) for the row corresponding to country i's own short-term debt (i.e., $n = i$ and $l = S$) is

$$\begin{aligned} 1 =& \mathbb{E}_{n,t}[\exp(\log(\beta) - \gamma\Delta c_{n,t+1} + r_{t+1}(n,S) - \Delta b_{n,t+1})] \\ \approx& \exp\Big(\log(\beta) - \gamma\mathbb{E}_{n,t}[\Delta c_{n,t+1}] + \mathbb{E}_{n,t}[r_{t+1}(n,S) - \Delta b_{n,t+1}] \\ &+ \frac{\operatorname{Var}_{n,t}(\gamma\Delta c_{n,t+1} + \Delta b_{n,t+1})}{2}\Big). \end{aligned} \tag{A12}$$

Equation (12) follows from taking logarithms of both sides and rearranging.

The Euler equations (A11) are an implicit solution to the portfolio choice problem. Instead, we approximate the objective function to obtain an explicit solution. Maximizing the objective function (A10) is equivalent to maximizing its monotone transformation:

$$\begin{aligned} \frac{\log\left(\mathbb{E}_{i,t}\left[C_{i,t}^{1-\gamma}\right]\right)}{1-\gamma} \approx& \mathbb{E}_{i,t}[c_{i,t+1}] + \frac{(1-\gamma)\operatorname{Var}_{i,t}(c_{i,t+1})}{2} \\ \approx& \log(A_{i,t}) + r_{i,t+1}(0) + \boldsymbol{w}_{i,t}'\left(\boldsymbol{\mu}_{i,t} + \frac{\boldsymbol{\sigma}_{i,t}^2}{2}\right) - \frac{\gamma\boldsymbol{w}_{i,t}'\boldsymbol{\Sigma}_{i,t}\boldsymbol{w}_{i,t}}{2}. \end{aligned} \tag{A13}$$

The second line follows from equation (A9) and an approximation of log real portfolio return (Campbell and Viceira 2002, equation 2.23) as

$$r_{i,t+1} \approx r_{i,t+1}(0) + \boldsymbol{w}_{i,t}'\left(\overline{\boldsymbol{r}}_{i,t+1} - r_{i,t+1}(0) + \frac{\boldsymbol{\sigma}_{i,t}^2}{2}\right) - \frac{\boldsymbol{w}_{i,t}'\boldsymbol{\Sigma}_{i,t}\boldsymbol{w}_{i,t}}{2}. \tag{A14}$$

Differentiating equation (A13) with respect to $\boldsymbol{w}_{i,t}$, the optimal portfolio is

$$\text{(A15)} \qquad \boldsymbol{w}_{i,t} = \frac{1}{\gamma}\boldsymbol{\Sigma}_{i,t}^{-1}\left(\boldsymbol{\mu}_{i,t} + \frac{\boldsymbol{\sigma}_{i,t}^{2}}{2}\right).$$

The Woodbury matrix identity implies that the inverse of the covariance matrix (A6) is

$$\text{(A16)} \qquad \boldsymbol{\Sigma}_{i,t}^{-1} = \operatorname{diag}(\boldsymbol{\omega})^{-1}\left(\mathbf{I} - \frac{\boldsymbol{\Omega}_{i,t}\boldsymbol{\Omega}_{i,t}'\operatorname{diag}(\boldsymbol{\omega})^{-1}}{1 + \boldsymbol{\Omega}_{i,t}'\operatorname{diag}(\boldsymbol{\omega})^{-1}\boldsymbol{\Omega}_{i,t}}\right).$$

Therefore, the optimal portfolio weight on asset class l in country n is

$$\text{(A17)} \qquad w_{i,t}(n,l) = \frac{1}{\gamma\omega(l)}\left(\mu_{i,t}(n,l) + \frac{\sigma_{i,t}^{2}(n,l)}{2} - \kappa_{i,t}\Omega_{i,t}(n,l)\right),$$

where

$$\text{(A18)} \qquad \kappa_{i,t} = \frac{\boldsymbol{\Omega}_{i,t}'\operatorname{diag}(\boldsymbol{\omega})^{-1}(\boldsymbol{\mu}_{i,t} + \boldsymbol{\sigma}_{i,t}^{2}/2)}{1 + \boldsymbol{\Omega}_{i,t}'\operatorname{diag}(\boldsymbol{\omega})^{-1}\boldsymbol{\Omega}_{i,t}}.$$

Equation (A17) implies higher portfolio weights on assets with higher expected returns or smaller factor loadings (i.e., lower risk).

D. Characteristics-Based Asset Demand

Let $\boldsymbol{x}_{i,t}(n)$ be a vector of observed characteristics that investor i uses to form beliefs about the risk of country n, including a constant to capture the intercept. Let $\psi_{i,t}(n,l)$ be a scalar that represents characteristics unobserved by the econometrician that investor i uses to form beliefs about the risk of asset class l in country n. We model the risk of asset class l in country n as a function of the observed and unobserved characteristics:

$$\text{(A19)} \qquad \frac{\sigma_{i,t}^{2}(n,l)}{2} - \kappa_{i,t}\Omega_{i,t}(n,l) = \boldsymbol{\Psi}_{l}'\boldsymbol{x}_{i,t}(n) + \psi_{i,t}(n,l).$$

We motivate our assumption with the fact that international bond and stock returns have a factor structure and that expected returns and factor loadings depend on asset characteristics (Fama and French 2012; Asness et al. 2013; Dahlquist and Hasseltoft 2013; Jotikasthira et al. 2015).

Substituting equation (A19) in equation (A17), investor i's portfolio weight on asset class l in country n is

$$\text{(A20)} \qquad w_{i,t}(n,l) = \lambda_{l}\mu_{i,t}(n,l) + \boldsymbol{\Lambda}_{l}'\boldsymbol{x}_{i,t}(n) + \epsilon_{i,t}(n,l),$$

where

$$\lambda_l = \frac{1}{\gamma\omega(l)}, \ \mathbf{\Lambda}_l = \frac{\mathbf{\Psi}_l}{\gamma\omega(l)}, \ \epsilon_{i,t}(n,l) = \frac{\psi_{i,t}(n,l)}{\gamma\omega(l)}. \tag{A21}$$

Equation (A20) is linear in expected returns and asset characteristics, while equation (31) that we use for the empirical application is log-linear. We refer to Koijen and Yogo (2019) for technical details about how more general assumptions imply the log-linear functional form.

Appendix B. Data Construction

A. Total Amounts Outstanding

Table B1 lists the 37 countries in our sample, grouped by MSCI region. For each country, the table reports the starting date and the data sources for debt and equity outstanding. The availability of the data on total amounts outstanding and asset prices limits the sample to 37 countries, consisting of all 22 countries in the MSCI World Index and 15 of 21 countries in the MSCI Emerging Markets Index. The availability of the US portfolio holdings data (U.S. Department of the Treasury 2003–2020) limits the starting date to 2003.

The data coverage improves over time with India and Russia entering in 2004, Malaysia entering in 2005, Colombia entering in 2007, Philippines entering in 2009, and China entering in 2015. Before entering, these countries are part of other countries on the investor side and the outside asset on the issuer side. Measurement also improves over time with the Organisation for Economic Cooperation and Development (2003–2020) covering Brazilian debt from 2009 and Israeli debt from 2010.

From the Organisation for Economic Cooperation and Development (2003–2020), we use Table 720 on the Non-Consolidated Financial Balance Sheets in US dollars, based on the 2008 System of National Accounts. The relevant variables are short-term debt outstanding (transaction code LF3SLINK), long-term debt outstanding (transaction code LF3LLINK), and equity outstanding (transaction code LF51LINK). From short- and long-term debt outstanding, we subtract the corresponding amount in international debt securities from the Bank for International Settlements (2003–2020) to isolate domestic debt securities. The purpose of this step is to use the available information on the currency composition of international debt securities. If available, we subtract other equity (transaction code LF519LINC) from equity outstanding to isolate common equity.

We apply the following rules to handle a few cases of missing data in the Organisation for Economic Cooperation and Development (2003–2020). For countries and years for which the breakdown between short- and long-term debt is not available, we multiply total debt (transaction code LF3LINC) in that year by the share in short- and long-term debt from

Table B1. Countries and Their Data Sources

Issuer	Sample starts	Data source: Debt	Data source: Equity
Developed markets: North America			
Canada	2003	OECD	OECD
United States	2003	OECD	OECD
Developed markets: Europe			
Austria	2003	OECD	OECD
Belgium	2003	OECD	OECD
Denmark	2003	OECD	OECD
Finland	2003	OECD	OECD
France	2003	OECD	OECD
Germany	2003	OECD	OECD
Israel	2003	OECD (from 2010)	OECD
		BIS (to 2009)	
Italy	2003	OECD	OECD
Netherlands	2003	OECD	OECD
Norway	2003	OECD	OECD
Portugal	2003	OECD	OECD
Spain	2003	OECD	OECD
Sweden	2003	OECD	OECD
Switzerland	2003	OECD	OECD
United Kingdom	2003	OECD	OECD
Developed markets: Pacific			
Australia	2003	BIS	WB
Hong Kong	2003	BIS	WB
Japan	2003	OECD	OECD
New Zealand	2003	BIS	OECD
Singapore	2003	BIS	WB
Emerging markets			
Brazil	2003	OECD (from 2009)	OECD
		BIS (to 2008)	
China	2015	BIS	WB
Colombia	2007	OECD	OECD
Czech Republic	2003	OECD	OECD
Greece	2003	OECD	OECD
Hungary	2003	OECD	OECD
India	2004	BIS	WB
Malaysia	2005	BIS	WB
Mexico	2003	OECD	OECD
Philippines	2009	BIS	WB
Poland	2003	OECD	OECD
Russia	2004	BIS	OECD
South Africa	2003	BIS	WB
South Korea	2003	OECD	OECD
Thailand	2003	BIS	WB

For each country, this table reports the starting date and the data sources for debt and equity outstanding. The data sources are the Organisation for Economic Cooperation and Development (2003–2020), the Bank for International Settlements (2003–2020), and the World Bank (2003–2020).

the closest year for which the breakdown is available. For countries and years for which the breakdown between equity and fund shares is not available, we multiply total equity and fund shares (transaction code LF5LINC) in that year by the share in equity from the closest year for which the breakdown is available.

From the Bank for International Settlements (2003–2020), the relevant variables are short- and long-term debt outstanding in domestic debt securities by issuer. The issuers are general government, financial corporations, and nonfinancial corporations. For issuers for which the breakdown between short- and long-term debt is not available, we multiply total debt by the share in short- and long-term debt among issuers for which the breakdown is available. We aggregate across issuers to compute short- and long-term debt outstanding. For countries for which the BIS reports the face value of debt, we compute the market value by multiplying by the corresponding price per unit of face value.

We apply the following rules to handle a few cases of missing data in the Bank for International Settlements (2003–2020). For countries and years for which the breakdown between short- and long-term debt is not available, we multiply total debt in that year by the share in short- and long-term debt from the closest year for which the breakdown is available. For countries for which the BIS does not report domestic debt securities, we impute domestic debt securities as total debt securities minus international debt securities. We then multiply total debt by the share in short- and long-term debt among international debt securities.

We construct short- and long-term debt outstanding as the sum of domestic debt securities and international debt securities. We assume that domestic debt securities are in local currency. The BIS separates international debt securities into local versus foreign currency.

For countries that are not in the Organisation for Economic Cooperation and Development (2003–2020), we construct equity outstanding based on the market capitalization of listed domestic companies from the World Bank (2003–2020). For a few cases of missing data in the Organisation for Economic Cooperation and Development (2003–2020) and the World Bank (2003–2020), we splice equity outstanding backwards and forwards with the market equity from the MSCI (2003–2020).

To account for investments through tax havens, we restate the total amounts outstanding from the issuer's residency to nationality, based on the issuance-based restatement matrices of the Global Capital Allocation Project (Coppola et al. 2021). Since the data start in 2007, we extrapolate back to 2003 to cover our sample period. We apply the estimate for the euro area to each country in the euro area. We apply the estimate for total debt to short- and long-term debt. After restating from residency to nationality accounting, we aggregate total amounts outstanding by year, issuer country, asset class, and local versus foreign currency.

The total amounts outstanding are all market values in US dollars. We construct the face value of debt outstanding as the market value divided by the corresponding price per unit of face value. We construct the book value of equity outstanding as the market value divided by market-to-book equity.

B. International Portfolio Holdings

For US investors, we use Forms SHC/SHCA (U.S. Department of the Treasury 2003–2020), which contain foreign portfolio holdings by year, issuer country, asset class, and currency (i.e., US dollars, euros, Japanese yen, British pounds, and other). We define three asset classes as short-term debt, long-term debt, and common equity.

For other investor countries, we use the Coordinated Portfolio Investment Survey (International Monetary Fund 2003–2020a), which contain foreign portfolio holdings by year, investor country, issuer country, and asset class. The IMF does not report a further breakdown by currency. However, the IMF reports foreign portfolio holdings by investor country, asset class, and currency (i.e., US dollars, euros, Japanese yen, British pounds, and Swiss francs), which are aggregated across issuer countries. We use these data below to adjust for the currency composition. The IMF does not separately report equity and fund shares. We multiply total equity and fund shares by an estimate of the share in common equity from the Global Capital Allocation Project (Coppola et al. 2021).[5] Thus, we define three asset classes as short-term debt, long-term debt, and equity. We leave confidential holdings and small holdings less than $0.5 million as missing data.

We define offshore financial centers as countries whose ratio of portfolio assets to GDP is above five (Zoromé 2007, Table 8). They are Bermuda, the Cayman Islands, Guernsey, Ireland, the Isle of Man, Jersey, Luxembourg, and the Netherlands Antilles. Mutual funds and investment companies domicile in offshore financial centers because of favorable regulation and tax laws. The Coordinated Portfolio Investment Survey could double count investments through offshore financial centers, once as an investor country and again as an issuer country (International Monetary Fund 2002, p. 72). To eliminate double counting, we drop observations where the investor is an offshore financial center.

To account for investments through tax havens, we restate the portfolio holdings from the issuer's residency to nationality, based on the restatement matrices of the Global Capital Allocation Project. We use the restatement matrices based on enhanced fund holdings for

[5] To construct the share in common equity, Coppola et al. (2021) assume that any foreign portfolio holdings that the Coordinated Portfolio Investment Survey does not report are in fund shares. This assumption avoids the issue that the portfolio liabilities exceed the sum of foreign portfolio holdings in tax havens such as the Cayman Islands, Ireland, and Luxembourg (Zucman 2013). The working assumption is that these gaps of missing wealth are in fund shares and consequently outside our sample that focuses on common equity.

Norway and the United States; fund holdings for the euro area, Australia, Canada, Denmark, Norway, Sweden, Switzerland, and the United Kingdom; and issuance for the remaining countries. Since the data start in 2007, we extrapolate back to 2003 to cover our sample period. We apply the estimate for the euro area to each country in the euro area. We apply the estimate for total debt to short- and long-term debt.

After restating from residency to nationality accounting, we adjust for the currency composition in the Coordinated Portfolio Investment Survey. We use the aggregate portfolio holdings by currency to cap the portfolio holdings in the issuer's local currency. For example, if an investor's total short-term debt holdings across countries in the euro area exceed its aggregate short-term debt holdings in euros, we assume that the excess amount is short-term debt that is not in euros. Thus, an investor's short-term debt holdings in euros across countries in the euro area add up properly to its aggregate short-term debt holdings in euros. After this adjustment, we aggregate the portfolio holdings by year, issuer country, asset class, and local versus foreign currency.

We round up the restated portfolio holdings to $1,000, which is the minimum reported value in the Coordinated Portfolio Investment Survey, to winsorize tiny holdings. We also winsorize the left tail of outside assets so that the outside portfolio weight by investor and asset class is at least 0.1 percent.

C. Asset Characteristics

The World Bank (2003–2020) is our data source for the macro variables and population. To construct the real exchange rate, we use the purchasing power parity conversion factors for GDP in current international dollars, which we refer to as the relative price indices. We construct the relative price index for the euro area as a GDP-weighted average over the ten countries in our sample. For the asset demand estimation, we use GDP and GDP per capita at purchasing power parity in current international dollars. We construct inflation as log growth rate of the consumer price index.

We estimate equity volatility using monthly returns in US dollars on the MSCI Country Indexes from Datastream (Refinitiv 2003–2020). For each country and at each year-end, we estimate the standard deviation of monthly returns over the past 12 months. We annualize equity volatility by multiplying the monthly standard deviation by $\sqrt{12}$.

We use the long-term debt rating in local currency from Standard & Poors (2003–2020). We convert the rating to a continuous measure by fitting a smooth curve to the ten-year default rate (Standard & Poors 2018, Table 36): 0 for AAA to AA−, 0.0198 for A+, 0.0237 for A, 0.0284 for A−, 0.0341 for BBB+, 0.0409 for BBB, 0.0491 for BBB−, 0.0589 for BB+, 0.0707 for BB, 0.0848 for BB−, 0.1017 for B+, 0.1220 for B, 0.1463 for B−, 0.1755 for CCC+, 0.2106 CCC, 0.2526 CCC−, and 0.3030 for CC. Our measure is −1 times the ten-year default rate, so that a higher value implies a higher rating.

Appendix C. Computational Details

A. Aggregate Demand Elasticity

Let $Q_{i,t}(n,l) = A_{i,t}w_{i,t}(n,l)/(P_t(n,l)E_t(n))$ be investor i's holding of asset class l in country n in year t. We write investor i's wealth in year t as

$$A_{i,t} = O_{i,t} + \sum_{l\in\{S,L,E\}}\sum_{n=1}^{N} P_t(n,l)E_t(n)Q_{i,t}(n,l). \tag{C1}$$

Differentiating with respect to $p_t(n,l)$, we have

$$\frac{\partial A_{i,t}}{\partial p_t(n,l)} = P_t(n,l)E_t(n)Q_{i,t}(n,l) = A_{i,t}w_{i,t}(n,l). \tag{C2}$$

The aggregate demand elasticity with respect to price is

$$1 - \frac{\partial \log\left(\sum_{i=1}^{I} A_{i,t}w_{i,t}(n,l)\right)}{\partial p_t(n,l)} = 1 - \frac{\sum_{i=1}^{I} A_{i,t}(w_{i,t}(n,l)^2 + \partial w_{i,t}(n,l)/\partial p_t(n,l))}{\sum_{i=1}^{I} A_{i,t}w_{i,t}(n,l)},$$

which we compute numerically.

B. Counterfactual Wealth in the Variance Decomposition

We write investor i's intertemporal budget constraint as

$$A_{i,t+1} = O_{i,t+1} + \sum_{l\in\{S,L,E\}}\sum_{n=1}^{N}(A_{i,t}w_{i,t}(n,l) + F_{i,t+1}(n,l))\frac{P_{t+1}(n,l)E_{t+1}(n)}{P_t(n,l)E_t(n)}. \tag{C3}$$

This equation defines the portfolio flow $F_{i,t+1}(n,l)$ into asset class l in country n in year $t+1$. We assume that the portfolio flow occurs at the beginning (rather than the end) of year $t+1$, so that it earns the return in year $t+1$.

Let $\boldsymbol{E}_C$ be a column vector of dimension $N-12$, whose nth element is the counterfactual exchange rate $E_C(n)$. Let $\boldsymbol{P}_C$ be a matrix of dimension $(3N-11)\times 3$, whose (n,l)th element is the counterfactual asset price $P_C(n,l)$. Based on the intertemporal budget constraint, we define investor i's counterfactual wealth as

$$A_{i,C} = O_{i,C} + \sum_{l\in\{S,L,E\}}\sum_{n=1}^{N}(A_{i,t}w_{i,t}(n,l) + F_{i,C}(n,l))\frac{P_C(n,l)E_C(n)}{P_t(n,l)E_t(n)}. \tag{C4}$$

The second term on the right side is the counterfactual capital gain relative to the initial wealth at the beginning of year $t+1$. Given our timing assumption for portfolio flows, counterfactual wealth is strictly positive for any counterfactual exchange rates and asset prices since $A_{i,t}w_{i,t}(n,l) + F_{i,C}(n,l) \geq 0$.

We have two objectives with respect to outside assets. First, the sum of outside wealth across investors must remain constant to satisfy market clearing. Second, substitution across inside assets should primarily determine exchange rates and asset prices, and outside assets should only play a passive role. To satisfy both objectives, we define investor i's counterfactual portfolio weight on asset class l in country n as

$$\text{(C5)} \quad w_{i,C}(n,l;\boldsymbol{E}_C,\boldsymbol{P}_C,\tau_{i,C}) = \frac{\delta_{i,C}(n,l;\boldsymbol{E}_C,\boldsymbol{P}_C)\exp(-\tau_{i,C})}{1+\sum_{m=0}^{N}\delta_{i,C}(m,l;\boldsymbol{E}_C,\boldsymbol{P}_C)\exp(-\tau_{i,C})} w_{i,C}(l;\boldsymbol{E}_C,\boldsymbol{P}_C).$$

The parameter $\tau_{i,C}$ is a counterfactual demand shifter such that

$$\text{(C6)} \quad A_{i,C} = \frac{O_{i,C}}{1-\sum_{l\in\{S,L,E\}}\sum_{n=1}^{N} w_{i,C}(n,l;\boldsymbol{E}_C,\boldsymbol{P}_C,\tau_{i,C})}.$$

Given counterfactual wealth $A_{i,C}$, we can increase $\tau_{i,C}$ to increase counterfactual outside wealth $O_{i,C}$ to keep it constant.

The counterfactual exchange rates and asset prices satisfy the market clearing equations

$$\text{(C7)} \quad P_C(n,l)E_C(n)Q_C(n,l) = \sum_{i=1}^{I} A_{i,C}w_{i,C}(n,l;\boldsymbol{E}_C,\boldsymbol{P}_C,\tau_{i,C})$$

and $N-11$ equations for the model of short-term rates (18). We solve jointly for the counterfactual exchange rates and asset prices and the set of counterfactual demand shifters that keep the outside wealth constant for all investors.

In the first step of the variance decomposition, we change the portfolio flows from $F_{i,C}(n,l) = 0$ to $F_{i,C}(n,l) = F_{i,t+1}(n,l)$ and the asset quantities from $Q_C(n,l) = Q_t(n,l)$ to $Q_C(n,l) = Q_{t+1}(n,l)$. We then compute the counterfactual exchange rates and asset prices that clear all markets. In the second step, we change the macro variables, which update the portfolio weights and the short-term rates. In the third step, we change latent demand and outside wealth from $O_{i,C} = O_{i,t}$ to $O_{i,C} = O_{i,t+1}$, which update the portfolio weights and the short-term rates. After the third step, the counterfactual exchange rates, asset prices, and wealth are equal to their realizations in year $t+1$. The counterfactual demand shifters are equal to zero.

Appendix D. Supplemental Tables and Figures

Table D1. Estimated Demand for Equity

Variable	Coefficient
Expected return	10.31
	(0.78)
Log GDP	1.34
	(0.02)
Log GDP per capita	3.94
	(0.21)
Inflation	-17.22
	(1.89)
Volatility	-4.92
	(0.33)
Rating	11.63
	(1.16)
Distance	-0.15
	(0.01)
Indicator variables:	
Domestic ownership	7.68
	(0.14)
Reserves	-2.84
	(0.14)
Other countries	-1.87
	(0.10)
Constant	-54.14
	(2.37)
F-statistic for weak IV	531
Observations	23,779

Expected returns are the predicted values from a predictive regression, imposing a coefficient of -0.09 on log market-to-book equity. The sovereign debt rating is a continuous measure equal to -1 times the ten-year default rate. The model includes year fixed effects. Heteroskedasticity-robust standard errors are reported in parentheses. The critical value for a test of weak instruments at the 5 percent significance level is 16.38 (Stock and Yogo 2005). The annual sample period is 2003 to 2011.

Table D2. Regressions of Changes in Exchange Rates and Asset Prices

Variable	Exchange rate	Short-term debt	Long-term debt	Equity
Log GDP	0.22	-0.03	0.18	-0.12
	(1.11)	(0.15)	(0.11)	(1.88)
Log GDP per capita	-0.22	0.43	-0.06	-0.05
	(1.15)	(0.15)	(0.13)	(2.06)
Inflation	-0.08	0.17	-0.25	-0.29
	(0.95)	(0.09)	(0.08)	(0.70)
Volatility	-0.19	-0.14	-0.14	-0.55
	(0.11)	(0.02)	(0.01)	(0.16)
Rating	-0.01	-0.08	-0.24	0.03
	(1.31)	(0.13)	(0.18)	(1.57)
Relative price index	0.20	-0.02	0.05	0.03
	(0.41)	(0.03)	(0.03)	(0.45)
R^2	0.08	0.29	0.15	0.47
Observations	399	416	603	603

All regressors are in first differences. The sovereign debt rating is a continuous measure equal to -1 times the ten-year default rate. All coefficients are standardized. Heteroskedasticity-robust standard errors are reported in parentheses. The observations are value-weighted by the market weights within year and asset class. The annual sample period is 2003 to 2020.

Table D3. Predictive Regressions: 2003–2011

Variable	Exchange rate	Long-term debt	Equity
Log asset price		-0.62	-0.28
		(0.19)	(0.29)
Log real exchange rate	-0.46	-0.47	-1.45
	(0.14)	(0.12)	(0.61)
Constant		-0.06	0.31
		(0.04)	(0.22)
R^2	0.30	0.34	0.27
Observations	202	310	310

Log asset price is minus maturity times log yield for long-term debt and log market-to-book for equity. All models include country fixed effects. Robust standard errors clustered by year are reported in parentheses. The annual sample period is 2003 to 2011.

Table D4. Estimated Demand within Asset Class: 2003–2011

Variable	Short-term debt	Long-term debt	Equity
Expected return	1.58	1.39	2.16
	(0.97)	(0.45)	(0.22)
Log GDP	1.20	1.11	1.29
	(0.03)	(0.02)	(0.02)
Log GDP per capita	2.06	1.83	2.57
	(0.26)	(0.13)	(0.17)
Inflation	-0.20	0.62	-10.55
	(2.54)	(1.66)	(1.58)
Volatility	-2.19	-0.41	-4.61
	(0.47)	(0.36)	(0.38)
Rating	7.24	6.81	15.11
	(1.91)	(1.99)	(2.07)
Distance	-0.14	-0.20	-0.19
	(0.01)	(0.01)	(0.01)
Indicator variables:			
Domestic ownership	8.32	6.09	7.51
	(0.20)	(0.12)	(0.16)
Reserves	0.49	0.07	-2.80
	(0.16)	(0.14)	(0.17)
Other countries	1.72	0.84	-1.52
	(0.13)	(0.08)	(0.10)
Constant	-33.98	-30.96	-37.23
	(2.70)	(1.37)	(1.76)
F-statistic for weak IV	195	819	952
Observations	9,433	10,874	11,233

Expected returns are the predicted values from the predictive regressions in Table D3. The sovereign debt rating is a continuous measure equal to -1 times the ten-year default rate. All models include year fixed effects. Heteroskedasticity-robust standard errors are reported in parentheses. The critical value for a test of weak instruments at the 5 percent significance level is 16.38 (Stock and Yogo 2005). The annual sample period is 2003 to 2011.

Table D5. Estimated Demand across Asset Classes: 2003–2011

Variable	Symbol	Estimate
Log outside portfolio weight:		
Short-term debt	ρ_S	0.23
		(0.05)
Long-term debt	ρ_L	0.53
		(0.07)
Equity	ρ_E	0.54
		(0.06)
Indicator variables:		
Short-term debt	α_S	-0.73
		(0.29)
Long-term debt	α_L	0.96
		(0.27)
F-statistic for weak IV		436
Observations		656

Heteroskedasticity-robust standard errors are reported in parentheses. The annual sample period is 2003 to 2011.

Table D6. Estimated Model of Short-Term Rates: 2003–2011

Variable	Coefficient
Log GDP	0.06
	(0.02)
Log GDP per capita	-0.07
	(0.03)
Inflation	-0.12
	(0.03)
Volatility	0.01
	(0.01)
Rating	0.07
	(0.07)
Constant	0.14
	(0.08)
Observations	211

The model includes country fixed effects. Heteroskedasticity-robust standard errors are reported in parentheses. The annual sample period is 2003 to 2011.

Table D7. Variance Decomposition of Exchange Rates and Asset Prices: 2012–2020

	In sample				Out of sample			
Change in	Exchange rate	Short-term rate	Long-term yield	Market-to-book equity	Exchange rate	Short-term rate	Long-term yield	Market-to-book equity
Portfolio flows	0.21		0.71	0.30	0.37		1.34	0.39
	(0.05)		(0.29)	(0.15)	(0.09)		(0.55)	(0.22)
Macro variables	0.21	0.17	0.11	0.16	0.05	0.26	0.13	0.26
	(0.08)	(0.06)	(0.11)	(0.06)	(0.08)	(0.08)	(0.13)	(0.08)
Latent demand	0.58	0.83	0.17	0.53	0.58	0.74	-0.47	0.35
	(0.09)	(0.06)	(0.37)	(0.11)	(0.08)	(0.08)	(0.65)	(0.17)
Reserves	0.12		0.06	0.00	0.11		0.08	0.01
	(0.02)		(0.03)	(0.02)	(0.03)		(0.04)	(0.02)
North America	0.09	0.37	-0.08	0.10	-0.02	0.30	-0.41	-0.02
	(0.08)	(0.14)	(0.26)	(0.10)	(0.14)	(0.12)	(0.54)	(0.15)
Europe	0.17	0.06	0.25	0.21	0.20	0.06	0.19	0.14
	(0.05)	(0.05)	(0.09)	(0.05)	(0.08)	(0.06)	(0.10)	(0.06)
Pacific	0.22	0.02	-0.05	0.03	0.33	0.01	-0.03	-0.01
	(0.06)	(0.01)	(0.04)	(0.03)	(0.10)	(0.01)	(0.07)	(0.04)
Emerging markets	-0.04	0.39	0.00	0.20	-0.05	0.36	-0.29	0.22
	(0.03)	(0.11)	(0.12)	(0.07)	(0.05)	(0.11)	(0.23)	(0.12)
Other countries	0.02		0.00	0.00	0.01		-0.01	0.00
	(0.01)		(0.01)	(0.01)	(0.01)		(0.01)	(0.00)
Observations	221	230	329	329	221	230	329	329

Heteroskedasticity-robust standard errors are reported in parentheses. The observations are value-weighted by the market weights within year and asset class. The annual sample period for the asset demand estimation is 2003 to 2011, reported in Tables D4 and D5. The annual sample period for the variance decomposition is 2012 to 2020.