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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 analyze the equilibrium relation between international portfolio holdings and flows, exchange rates, and asset prices across all countries. We introduce a nested logit model of asset demand, for which we develop a new identification strategy by instrumental variables. Averaged across years and issuer countries, the demand elasticities are 27.9 for short-term debt, 3.2 for long-term debt, and 1.2 for equity. These demand elasticities are empirical targets for international macro models that feature inelastic demand to resolve longstanding puzzles in international finance. We use the estimated demand system 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 yields on US assets. In units of annual expected returns, the convenience yield is 1.41 percent on the US dollar, 2.71 percent on US long-term debt, and 0.50 percent on US equity.

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I. Introduction

We develop an asset demand system to analyze the equilibrium relation between international portfolio holdings and flows, exchange rates, short-term rates, long-term yields, and equity prices across all countries. We can represent the equilibrium of an international macro model as an asset demand system, which consists of consumption Euler equations, optimal portfolios, and market clearing. However, the optimal portfolios in a traditional model do not explain features such as the gravity effect and home bias in international portfolio holdings data (Portes, Rey, and Oh 2001; Portes and Rey 2005). Therefore, we replace the optimal portfolios with asset demand functions that match international portfolio holdings. In the resulting asset demand system, portfolio flows, shifts in asset demand through macro variables, and shifts in latent demand (i.e., the residual component of demand shifters) explain all movements in exchange rates and asset prices. Thus, we can reinterpret the exchange rate disconnect (Meese and Rogoff 1983) as a fact that shifts in asset demand through macro variables explain much less variation than portfolio flows and shifts in latent demand. Furthermore, the asset demand system tells us which countries' latent demand is important for explaining exchange rates and asset prices.

We introduce a nested logit model of asset demand with substitution across countries in the inner nest and across asset classes in the outer nest. The nested logit model has more flexible substitution effects than the logit model of asset demand, which Koijen and Yogo (2019) derive from a portfolio choice model with a factor structure in returns. Within each asset class, the allocation across countries depends on asset prices (equivalently, yields in the case of debt) and real exchange rates through expected returns. Asset demand also depends on macro variables such as gross domestic product (GDP), GDP per capita, inflation, equity volatility, and the sovereign debt rating; the bilateral distances between investor and issuer countries to capture the gravity effect; and an indicator variable for domestic ownership to capture home bias. Finally, asset demand depends on latent demand, which captures heterogeneous beliefs about risk exposure across investors and assets.

We develop a new identification strategy to estimate the nested logit model of asset demand by instrumental variables. To construct an instrument for the inner nest, we apply the core principle of identification in asset pricing, which is that an exogenous component of demand shifters for a group of investors generates variation in residual supply that identifies the demand elasticity for another group of investors. We isolate cross-sectional variation in the residual supply, based on the size distribution of countries and the bilateral distances between them. We explain the intuition for the identification strategy through an example. In the long-term debt market, the predicted supply of Dutch debt is similar to that of

Australian debt because they are similar in size as measured by a weighted average of GDP and population. However, the predicted demand for Dutch debt is much higher than that for Australian debt through the gravity effect because the Netherlands neighbors large investor countries in Europe. Thus, US investors face lower expected returns on Dutch 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 lower residual supply and consequently higher asset prices and/or real exchange rates.

We estimate the asset demand system on international portfolio holdings data across 37 countries and three asset classes (i.e., short-term debt, long-term debt, and equity) from 2003 to 2020. The International Monetary Fund (2003–2020a) 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 split local and foreign currency debt. We aggregate assets outside of the 37 countries and foreign currency debt into an outside asset for each asset class.

Averaged across years and issuer countries, the demand elasticities are 27.9 (1.9) for short-term debt, 3.2 (0.4) for long-term debt, and 1.2 (1.1) for equity with the standard errors in parentheses. That is, the aggregate demand for a country's equity decreases by 1.2 percent per one percent increase in its price. These demand elasticities are empirical targets for international macro models that feature inelastic demand and asset demand shocks unrelated to fundamentals to resolve longstanding puzzles in international finance (Gabaix and Maggiori 2015; Itskhoki and Mukhin 2021; Gourinchas, Ray, and Vayanos 2022; Kekre and Lenel 2024). 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, Fu, and Li 2023), and US stocks (Chang, Hong, and Liskovich 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.

Since the international portfolio holdings data are annual, we can use the estimated demand system to analyze any variation in exchange rates and asset prices at an annual or lower frequency. In the first application, we develop a variance decomposition to generate informative moments to test and to help design international macro models, following a long tradition in asset pricing (Campbell and Shiller 1988). 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. On the one hand, latent demand is relatively more important for exchange rates, short-term rates, and equity prices. Latent demand explains 82 percent of the variation in exchange rates, of which foreign exchange reserves explain 10 percent. Latent demand explains 86 percent of the variation in short-term rates. Latent demand explains 60 percent of the variation in log market-to-book equity, of which North American investors explain 13 percent and European investors explain 26 percent. On the other hand, portfolio flows and the macro variables are relatively more important for long-term yields. Portfolio flows explain 54 percent, and the macro variables explain 43 percent of the variation in long-term yields.

In the second application, we use the same variance decomposition to interpret 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 46 percent, and latent demand explains 32 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 74 percent of the variation in the Portuguese long-term yield. European investors alone explain 98 percent of the variation in the Italian long-term yield and 65 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. By focusing on particular countries and asset classes, we can use the asset demand system to interpret other economic events such as low-frequency movements in government debt (Fang, Hardy, and Lewis 2022), the US net foreign asset position (Jiang, Richmond, and Zhang 2024), and the US dollar (Jiang, Richmond, and Zhang 2025).

In the third application, we estimate the convenience yields 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, Krishnamurthy, and Lustig 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 5.23 percent higher. Consequently, the expected annual return on a value-weighted portfolio of foreign short-term debt (i.e., long non-US dollar currencies) is 1.41 percent lower. The US long-term yield is 0.73 percent higher, and its expected annual return is 2.71 percent higher.

The US market-to-book equity is 3.35 percent lower, and its expected annual return is 0.50 percent higher. To summarize in units of expected annual returns, the mean convenience yield is 1.41 percent on the US dollar, 2.71 percent on US long-term debt, and 0.50 percent on US equity.

A. Related Literature

Koijen and Yogo (2019) introduced demand system asset pricing as a new approach to understand financial markets by estimating an asset demand system on portfolio holdings data and analyzing the equilibrium relation between portfolio holdings and flows, asset prices, and asset characteristics. This is the first paper (posted online on June 18, 2019) to extend demand system asset pricing to international finance. Related papers estimate an asset demand system for a subset of assets that we consider including US Treasury debt (Chaudhary, Fu, and Zhou 2024; Jansen, Li, and Schmid 2024), US corporate debt (Darmouni, Siani, and Xiao 2022; Bretscher et al. 2023; Chaudhary, Fu, and Li 2023), euro-area government debt (Koijen et al. 2021), and international government and corporate debt (Fang, Hardy, and Lewis 2022; Nenova 2025). Applying the variance decomposition that we develop in this paper, Jiang, Richmond, and Zhang (2024) explain low-frequency movements in the US net foreign asset position (Atkeson, Heathcote, and Perri 2022), and Jiang, Richmond, and Zhang (2025) explain low-frequency movements in the US dollar.

The core structure of a two-country general equilibrium model consists of four optimality equations for consumption and portfolio choice and market clearing of two consumption goods and two bonds. In this context, this paper relates to three modeling approaches in international finance. First, the portfolio balance models replace the optimality equations with direct specifications of interest rates and asset demand functions (Kouri 1983; Blanchard, Giavazzi, and Sa 2005). Second, a group of international macro models assumes market segmentation such that each country can invest only in the domestic bond, and only an arbitrageur can trade across countries (Gabaix and Maggiori 2015; Itskhoki and Mukhin 2021; Kekre and Lenel 2024). A preferred habitat model works similarly, where only an arbitrageur can trade across countries and maturities (Gourinchas, Ray, and Vayanos 2022; Greenwood et al. 2023). Third, Hau and Rey (2006) extend the two-country model to equity markets and introduce a foreign exchange market. Relative to this mostly theoretical literature, we design an asset demand system across multiple countries and asset classes for estimation on international portfolio holdings data. Although we do not assume market segmentation, we directly specify asset demand functions with flexible demand elasticities.

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, Le, and Lundblad 2015), and currency returns (Lustig, Roussanov, and Verdelhan 2011). These papers find both common and local factors across countries within each asset class. Asness, Moskowitz, and Pedersen (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.

B. Outline

The remainder of the paper is organized as follows. In Section II, we develop an asset demand system for international finance. 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 use the estimated demand system to develop a variance decomposition of exchange rates and asset prices. We also present a case study of the European sovereign debt crisis. In Section VI, we estimate the convenience yields on US assets. Section VII concludes.

II. Global Demand System

We develop an asset demand system for international finance in four steps. First, we model expected returns through a predictive regression of future returns on the asset price and the real exchange rate. Second, we model short-term rates as a function of macro variables. Third, we introduce a nested logit model of asset demand with substitution across countries in the inner nest and across asset classes in the outer nest. Finally, we complete the asset demand system with market clearing across all countries and asset classes. We address relevant empirical issues such as foreign currency debt, currency unions, and fixed exchange rates.

In Appendix A, we develop a two-country version of the asset demand system to clarify the mechanics of equilibrium in a simpler setting. The core structure of a two-country general equilibrium model consists of four optimality equations for consumption and portfolio choice and market clearing of two consumption goods and two bonds. We replace the consumption Euler equations with a model of interest rates, the optimal portfolios with asset demand functions, and endogenous consumption choice with exogenous portfolio flows. In Appendix B, we develop a general equilibrium model with multiple countries and asset classes as a microfoundation to help design our asset demand system.

We use lowercase letters to denote the logarithm of the corresponding uppercase variables. We use bold letters to denote column vectors or matrices. We denote the first difference operator as Δ. We denote the conditional expectation at time t as $\mathbb{E}_t$.

A. *Asset Markets*

We index the issuer countries as $n = 1, \ldots, N$. 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 in US dollars per country n's currency unit at time t. Then $E_t(n)/V_t(n)$ 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. $Q_t(n, L)$ 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 $E_t(n)P_t(n, L)Q_t(n, L)$ is the market value of debt outstanding in US dollars.

B. *Expected Returns*

We index the investor countries as $i = 1, \ldots, I$. We assume that investors care about returns in their local currency for the purposes of portfolio choice. 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 nominal return in US dollars is $r_{t+1}(n, l) + \Delta e_{t+1}(n)$. We estimate a predictive regression for each asset class:

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

where $\iota_{n,l}$ represent 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 mean reversion implies a coefficient $\theta_l \geq 0$. A high log real exchange rate $e_t(n) - v_t(n)$ predicts depreciation of the nominal exchange rate under purchasing power parity, which implies a coefficient $\Theta_l \geq 0$.

The predicted values from the predictive regression (1) are expected returns in US dollars. We construct the expected excess return in investor i's local currency as

$$\mathbb{E}_t[r_{t+1}(n,l) + \Delta e_{t+1}(n) - r_{t+1}(i,S) - \Delta e_{t+1}(i)] = \mu_{i,t}(n,l) + \iota_{n,l} - \iota_{i,S}, \tag{2}$$

where

$$\mu_{i,t}(n,l) = -\theta_l p_t(n,l) - \Theta_l(e_t(n) - v_t(n)) + \theta_S p_t(i,S) + \Theta_S(e_t(i) - v_t(i)). \tag{3}$$

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 (3) is the expected UK equity return in yen minus the Japanese short-term rate in yen.

C. Model of Short-Term Rates

Let $\boldsymbol{z}_t(n)$ be a vector of the characteristics of country n, including a constant to capture the intercept. Let $\pi_t(n)$ be a latent state variable for country n, unobserved by the econometrician, that relates to the distribution inflation and consumption growth. We model the short-term debt price in country n as

$$p_t(n,S) = \mathbf{\Pi}'\boldsymbol{z}_t(n) + \pi_t(n). \tag{4}$$

In Appendix B, we derive this equation from the consumption Euler equation.

D. 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 (3) 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 debt issued by one of the N countries.

We introduce a nested logit model of asset demand to allow for imperfect substitution across asset classes. Investor i's portfolio weight on asset class l in country n at time t is

$$w_{i,t}(n,l) = w_{i,t}(n \mid l) w_{i,t}(l). \tag{5}$$

The inner nest $w_{i,t}(n \mid l)$ models how an investor substitutes across countries within an asset class. The portfolio weights sum to one within each asset class: $\sum_{n=0}^{N} w_{i,t}(n \mid l) = 1$. The outer nest $w_{i,t}(l)$ models how an investor substitutes across asset classes. The aggregate portfolio weights sum to one across all asset classes: $\sum_{l\in\{S,L,E\}} w_{i,t}(l) = 1$.

Let $E_t(n)P_t(n,l)Q_{i,t}(n,l) = A_{i,t}w_{i,t}(n,l)$ be investor i's US dollar holding of asset class l in country n in year t. Let $O_{i,t} = \sum_{l\in\{S,L,E\}} A_{i,t}w_{i,t}(0,l)$ be the outside wealth in US dollars. We treat the outside wealth as exogenous because we do not have information about its price versus quantity. Investor i's wealth in US dollars at time t is

$$\begin{aligned} A_{i,t} =& O_{i,t} + \sum_{l\in\{S,L,E\}} \sum_{n=1}^{N} E_t(n)P_t(n,l)Q_{i,t}(n,l) \\ =& \frac{O_{i,t}}{1 - \sum_{l\in\{S,L,E\}} \sum_{n=1}^{N} w_{i,t}(n,l)}. \end{aligned} \tag{6}$$

1. Demand within Asset Class

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

$$w_{i,t}(n \mid l) = \frac{\delta_{i,t}(n,l)}{1 + \sum_{m=1}^{N} \delta_{i,t}(m,l)}, \tag{7}$$

where

$$\delta_{i,t}(n,l) = \exp(\lambda_l \mu_{i,t}(n,l) + \boldsymbol{\Lambda}_l' \boldsymbol{x}_{i,t}(n) + \epsilon_{i,t}(n,l)). \tag{8}$$

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

$$w_{i,t}(0 \mid l) = \frac{1}{1 + \sum_{n=1}^{N} \delta_{i,t}(n,l)}. \tag{9}$$

In every portfolio choice model, asset allocation depends on differences in expected returns across assets. The expected excess return (3) 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 risk exposure across assets, which we model through the asset characteristics and latent demand. For example, 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). 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 exposure for the same asset. For example, investors believe that farther countries have higher risk because of informational frictions that increase in the bilateral distance. Similarly, latent demand captures heterogeneous beliefs about risk exposure across investors and assets.

2. Demand across Asset Classes

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

$$w_{i,t}(l) = \frac{\left(1 + \sum_{n=1}^{N} \delta_{i,t}(n,l)\right)^{\rho_l} \exp(\alpha_l + \xi_{i,t}(l))}{\sum_{k \in \{S,L,E\}} \left(1 + \sum_{n=1}^{N} \delta_{i,t}(n,k)\right)^{\rho_k} \exp(\alpha_k + \xi_{i,t}(k))}. \tag{10}$$

The first term inside the parentheses in the numerator, which is also the denominator in the inner nest (7), 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 (10) 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 (10) depends on asset-class fixed effects α_l and asset-class latent demand $\xi_{i,t}(l)$. Asset-class latent demand captures heterogeneous beliefs about risk exposure 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.

3. Special Cases

When $\rho_l = 1$ for all asset classes in equation (10), 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

$$w_{i,t}(n,l) = \frac{\delta_{i,t}(n,l)}{1 + \sum_{k \in \{S,L,E\}} \sum_{m=1}^{N} \delta_{i,t}(m,k)}. \tag{11}$$

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 (10), we have no substitution across asset classes. The portfolio weight on asset class l in country n at time t simplifies to

$$w_{i,t}(n,l) = \frac{\delta_{i,t}(n,l)}{1 + \sum_{m=1}^{N} \delta_{i,t}(m,l)} \frac{\exp(\alpha_l + \xi_{i,t}(l))}{\sum_{k \in \{S,L,E\}} \exp(\alpha_k + \xi_{i,t}(k))}. \tag{12}$$

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 wealth (6).

4. Restrictions on Demand Elasticities

A traditional model of portfolio choice under constant relative risk aversion utility and short-sale constraints implies a mean-variance portfolio (Markowitz 1952). If the returns satisfy a characteristics-based factor model, Koijen and Yogo (2019, Proposition 1) show that the mean-variance portfolio simplifies significantly because all information about the other asset prices and characteristics collapses to a scalar variable that is constant across assets. Under additional restrictions on the factor model, Koijen and Yogo (2019, Corollary 1) show that the mean-variance portfolio becomes a logit model of asset demand. Thus, the logit model is more restrictive than the mean-variance portfolio in theory. In practice, a factor model is a robust approach to estimating the optimal portfolio because of the bias-variance tradeoff, and the logit model closely approximates the optimal portfolio for the cross section of US stocks (Koijen and Yogo 2019, Appendix B).

The nested logit model allows for more flexible substitution effects than the logit model. The demand elasticities in the logit model depend on a single parameter. In our implementation of the nested logit model, the demand elasticities depend on three parameters in the inner nest (i.e., λ_S, λ_L, and λ_E) and three parameters in the outer nest (i.e., ρ_S, ρ_L, and ρ_E). Future research could propose an asset demand system with more flexible substitution effects than the nested logit model. However, an asset demand system with more parameters is not necessarily better because of the bias-variance tradeoff, and we need economically relevant benchmarks to evaluate its relative performance (Gabaix et al. 2024, 2025).

E. *Portfolio Flows*

We define portfolio flows as changes in the portfolio holdings in the absence of capital gains. We write investor i's intertemporal budget constraint from time t to $t+1$ as

$$A_{i,t+1} = O_{i,t+1} + \sum_{l \in \{S,L,E\}} \sum_{n=1}^{N} (A_{i,t} w_{i,t}(n,l) + F_{i,t}(n,l)) \frac{E_{t+1}(n) P_{t+1}(n,l)}{E_t(n) P_t(n,l)}. \tag{13}$$

Thus, $F_{i,t}(n,l)$ is the portfolio flow into asset class l in country n at the end of time t, which earns the return from time t to $t+1$.

F. *Market Clearing*

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

$$E_t(n) P_t(n,l) Q_t(n,l) = \sum_{i=1}^{I} A_{i,t} w_{i,t}(n,l). \tag{14}$$

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 weights (5) and wealth (6) depend on all exchange rates and asset prices. Importantly, the portfolio weights depend on the level of exchange rates and asset prices through the model of expected excess returns (3).

G. *Equilibrium*

The asset demand system consists of N equations for the model of short-term rates (4), the nested logit model of asset demand (5), and $3N$ market clearing equations (14). One of the market clearing equations (e.g., US short-term debt) 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 counterfactual experiments. 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.[1]

Let $\boldsymbol{e}_t$ be a vector of dimension $N - 12$ that stacks log exchange rates $e_t(n)$. Let $\boldsymbol{p}_t$ be a vector of dimension $3N - 11$ that stacks log asset prices $p_t(n, l)$. The asset demand system defines equilibrium exchange rates and asset prices as function of the state variables:

$$[\boldsymbol{e}_t', \boldsymbol{p}_t']' = \boldsymbol{m}(\boldsymbol{Q}_t, \boldsymbol{X}_t, \boldsymbol{O}_t, \boldsymbol{\pi}_t, \boldsymbol{\epsilon}_t, \boldsymbol{\xi}_t). \tag{15}$$

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

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 C 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

1. International Portfolio Holdings

We construct the portfolio holdings by investor country, issuer country, and asset class for 37 countries and other countries (i.e., the rest of the world) for 2003 to 2020 at an annual frequency. The 37 countries consist of all 22 countries in the MSCI World Index and 15 of

[1] 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.

21 countries in the MSCI Emerging Markets Index. As we describe in Appendix C, 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.

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 (Coppola et al. 2021). 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 use the available information on the currency composition to split local and foreign currency debt. 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 debt issued by one of the 37 countries. We aggregate the foreign currency debt as part of the outside asset because our data sources do not specify the currency when an asset is in foreign currency. For each investor country, outside wealth is the sum of outside assets across all asset classes.

2. Asset Prices

We use year-end values of exchange rates and asset prices to align with the year-end values of portfolio holdings. The relative price indices are the purchasing power parity conversion factors for GDP in current international dollars. Throughout the paper, both exchange rates and 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. The sample contains 26 independent short-term rates, accounting for the euro area and the two currency pegs. The long-term yields are five-year zero-coupon yields, which we assume is representative of international long-term debt holdings.[2] Equity prices are market-to-book equity for the MSCI Country Indexes.

3. 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.

To capture the gravity effect, 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.

4. Data Limitations

We discuss several data limitations that future research could address with improved public data or nonpublic data. Ito and McCauley (2020) hand collect the currency composition of foreign exchange reserves for nearly 60 central banks, reporting shares in US dollars, euros, Japanese yen, and British pounds. Future research could use these data to disaggregate the foreign exchange reserves and to assign them to the respective investor countries. This assignment requires additional assumptions to map currency to country because a foreign government could issue US dollar debt.

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

[2] 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).

with hand-collected data on domestic bank liabilities. Damgaard, Elkjaer, and Johannesen (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 to combine these data with domestic real investment. Moreover, foreign direct investment should be a separate asset class from public equity, leading to a difficult question of how to measure its price.

We do not adjust the debt holdings for currency hedging. Du and Huber (2024), 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 effectively 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 (2024) do not contain information about the counterparties. This measurement issue is important to resolve with the use of nonpublic data in future research.[3]

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

[3]If the debt holdings were adjusted for currency hedging, we anticipate that the effective portfolio weight on domestic debt would increase. In the asset demand estimation, we anticipate that the coefficient for the home bias would increase, but the effect on demand elasticities is less certain.

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.

Figure 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 not expect to see a downward-sloping demand curve from a scatter plot because the demand curve could shift 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 shift 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 (1) 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 (4).

We develop a new identification strategy to estimate the nested logit model of asset demand by instrumental variables. We start with an assumption that asset characteristics are exogenous, following the tradition of asset pricing in endowment economies (Lucas 1978) and the international asset pricing model in Appendix B. To construct an instrument for the inner nest, we apply the core principle of identification in asset pricing, which is that an exogenous component of demand shifters for a group of investors generates variation in residual supply that identifies the demand elasticity for another group of investors.

A. Expected Returns

We estimate the predictive regression (1) for each asset class. For short-term debt, we impose an 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 (3).

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. That is, the expected equity return decreases 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

1. Estimating Equations

We divide equation (7) by equation (9) and take logarithms to obtain

$$\log\left(\frac{w_{i,t}(n \mid l)}{w_{i,t}(0 \mid l)}\right) = \lambda_l \mu_{i,t}(n,l) + \boldsymbol{\Lambda}_l' \boldsymbol{x}_{i,t}(n) + \epsilon_{i,t}(n,l). \tag{16}$$

We have a panel regression 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 $\boldsymbol{\Lambda}_l$ are constant within asset class but vary across asset classes. Moreover, we restrict them to be constant across investors because of the limited sample size.

The identification strategy is based on three observations. First, we can estimate equation (16) based on the cross-sectional variation in expected returns across countries, given the assumption of constant coefficients within asset class. 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 generate an inelastic and time-invariant component of supply.

2. Example of Identification

We explain the intuition for identification of demand within asset class through a special case of the asset demand system. As illustrated in Figure 4, the United States ($i = U$) and Germany ($i = G$) are the investor countries. The Netherlands ($n = N$) and Australia ($n = A$) issue the same quantity of debt, represented by the outer circles in Figure 4. Each investor chooses a portfolio of Dutch debt, Australian debt, and an outside asset. For further simplification, we assume that all assets are in the same currency. We drop time subscripts to emphasize that identification requires only cross-sectional variation.

Applying the core principle of identification in asset pricing, an exogenous component of demand shifters for German investors generates variation in residual supply that identifies the demand elasticity for US investors. In Figure 4, German investors have a higher demand for Dutch than Australian debt through a gravity effect that depends on the bilateral distance. Therefore, US investors face a lower residual supply of Dutch than Australian debt, represented by the shaded donuts in Figure 4. The exclusion restriction is that the bilateral distance between Germany and the two issuer countries does not directly enter the US investors' demand, which becomes an instrument for the corresponding debt price.

Let $D_i(n)$ be the bilateral distance between countries i and n. Investor i's portfolio weight on country n relative to the outside asset is

$$\log\left(\frac{w_i(n)}{w_i(0)}\right) = -\lambda p(n) + \Lambda_1 D_i(n) + \Lambda_2 + \epsilon_i(n), \tag{17}$$

where the coefficient $\Lambda_1 < 0$ captures the gravity effect. We assume that the bilateral distance is exogenous, so that $\text{Cov}(\epsilon_i(n), D_i(n)) = 0$. Market clearing of country n's debt is

$$P(n)Q(n) = \sum_{i \in \{U,G\}} O_i \frac{w_i(n)}{w_i(0)}. \tag{18}$$

Substituting asset demand (17), we have an implicit function for the equilibrium price:

$$p(n) = m(Q(n), D_U(n), D_G(n), \boldsymbol{O}, \boldsymbol{\epsilon}(n)). \tag{19}$$

The equilibrium price (19), which depends on investor i's latent demand $\epsilon_i(n)$, is endogenous. We estimate equation (17) for US and German investors by instrumental variables, based on cross-sectional variation across Dutch and Australian debt. The exogeneity condition for identification is

$$\text{Cov}(\epsilon_i(n), D_j(n) \mid D_i(n)) = 0. \tag{20}$$

For investor i, the instrument for $p(n)$ is the bilateral distance between countries $j \neq i$ and n. The relevance condition is

$$\text{Cov}(p(n), D_j(n) \mid D_i(n)) \neq 0. \tag{21}$$

The intuition for the relevance condition is that US investors face a higher price on Dutch than Australian debt because of Germany's proximity to the Netherlands.

3. Identifying Assumptions

We extend the previous example to multiple countries and asset classes and allow for potential endogeneity of supply. When there are multiple countries, we need a procedure to aggregate the bilateral distances between all investor countries and an issuer country to construct the most relevant instrument. Thus, our description of the identification strategy requires more steps, but the core principle of identification remains the same.

We rewrite market clearing (14) as

$$P_t(n,l)\frac{E_t(n)}{V_t(n)} = \left(\underbrace{A_{i,t}w_{i,t}(n,l)}_{i\text{'s demand}} + \underbrace{\sum_{j\neq i} A_{j,t}w_{j,t}(n,l)}_{\text{other investors' demand}}\right)\underbrace{\frac{1}{V_t(n)Q_t(n,l)}}_{\text{supply}}. \tag{22}$$

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 exogenous shifts in the other investors' demand.

To construct the instrument, we first estimate an inelastic and time-invariant component of demand. For each asset class l, we estimate a panel regression:

$$\log\left(\frac{w_{i,t}(n \mid l)}{w_{i,t}(0 \mid l)}\right) = \Upsilon_l D_i(n) + \upsilon_l + \iota_{l,t} + \eta_{i,t}(n,l), \tag{23}$$

where υ_l is the common intercept and $\iota_{l,t}$ represents year fixed effects. Let

$$\widehat{\delta}_i(n,l) = \exp\left(\widehat{\Upsilon}_l D_i(n) + \widehat{\upsilon}_l\right), \tag{24}$$

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

$$\widehat{w}_{i,t}(n,l) = \frac{\widehat{\delta}_i(n,l)}{1+\sum_{m=1}^{N}\widehat{\delta}_i(m,l)}\widehat{w}(l). \tag{25}$$

We then estimate an inelastic and time-invariant component of supply. Let $\boldsymbol{z}_t(n)$ be a vector that contains log GDP at purchasing power parity and log population. For each asset class l, we estimate a panel regression:

$$v_t(n) + q_t(n,l) = \boldsymbol{\Psi}_l'\boldsymbol{z}_t(n) + \psi_l + \iota_{l,t} + \chi_t(n,l), \tag{26}$$

where ψ_l is the common intercept and $\iota_{l,t}$ represents year fixed effects. We construct the predicted log supply of asset class l in country n in year t as

$$v_t(n) + \widehat{q}_t(n,l) = \widehat{\boldsymbol{\Psi}}_l' \boldsymbol{z}_t(n) + \widehat{\psi}_l, \tag{27}$$

where $\widehat{\boldsymbol{\Psi}}_l$ and $\widehat{\psi}_l$ represent the corresponding estimated coefficients.

We then construct an instrument for $\mu_{i,t}(n,l)$ in equation (16) as

$$\mathrm{IV}_{i,t}(n,l) = \underbrace{\log\left(\sum_{j\neq i} \frac{O_{j,t}\widehat{w}_{j,t}(n,l)}{1-\sum_{l\in\{S,L,E\}}\sum_{m=1}^{N}\widehat{w}_{j,t}(m,l)}\right)}_{\text{predicted log demand}} - \underbrace{(v_t(n) + \widehat{q}_t(n,l))}_{\text{predicted log supply}}. \tag{28}$$

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 distances between investor and issuer countries. The predicted log demand for issuer n is high if there are large investor countries in close proximity.

Figure 5 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 predicted log supply of Dutch debt (NLD) is similar to that of Australian debt (AUS) because they are similar in size as measured by a weighted average of GDP and population. However, the predicted log demand for Dutch debt is much higher than that for Australian debt through the gravity effect because the Netherlands neighbors large investor countries in Europe. Thus, US investors face lower expected returns on Dutch 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 lower residual supply and consequently higher asset prices and/or real exchange rates.

To explain the functional form for the instrument (28), we go back to market clearing (22). Suppose that we take logarithms, delete investor i's demand, substitute wealth $A_{j,t}$ with equation (6), replace the portfolio weights $w_{j,t}(n,l)$ with the predicted portfolio weights $\widehat{w}_{j,t}(n,l)$, and replace log supply with the predicted log supply. Then equation (22) 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 size distribution of countries and the bilateral distances between them. The instrument is indexed by i because we isolate the exogenous variation in residual supply, by excluding investor i's demand.

4. Threats to Identification

Our identification strategy relies on the functional form of asset demand (16). 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 classes, 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 (16). However, the instrument (28) 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.

More generally, we could interact the expected return with asset characteristics to model heterogeneous demand elasticities across countries. The limited sample size of the country-level portfolio holdings data prevents us from estimating richer specifications. Future research could use investor-level portfolio holdings data or a different identification strategy to identify heterogeneous demand elasticities across countries.

5. 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. That is, the relative demand (i.e., $\log(w_{i,t}(n \mid l)/w_{i,t}(0 \mid l))$) for 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 imply 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 relative demand 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 relative demand 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 relative demand 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. That is, the relative demand for equity decreases by 15 percent per 1,000 km increase in the bilateral distance. A leading hypothesis for this gravity effect is informational frictions that increase in the bilateral distance (Portes, Rey, and Oh 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. That is, the relative demand for 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, Table 5.2). In Appendix E, we show that the asset demand estimation is not sensitive to sampling error in the predictive regression.

C. Demand across Asset Classes

1. Estimating Equations

We divide equation (10) for short- or long-term debt (i.e., $l = S, L$) by the same equation for equity (i.e., $l = E$), substitute out the inclusive value with the outside portfolio weight (9), and take logarithms to obtain

$$\log\left(\frac{w_{i,t}(l)}{w_{i,t}(E)}\right) = -\rho_l \log(w_{i,t}(0 \mid l)) + \rho_E \log(w_{i,t}(0 \mid E)) + \alpha_l + \xi_{i,t}(l). \tag{29}$$

We have a panel regression, 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., $w_{i,t}(0 \mid l)$ and $w_{i,t}(0 \mid E)$), which depend on exchange rates and asset prices, are endogenous with asset-class latent demand $\xi_{i,t}(l)$.

The identification strategy is based on two observations. First, we can estimate equation (29) based on cross-sectional variation in the outside portfolio weights across investors, given the assumption of constant coefficients across investors. Second, we can use an investors' own demand shifter to generate variation in the outside portfolio weight, given the structure of the nested logit model. In particular, we use an inelastic and time-invariant component of the outside portfolio weight due to investor-specific home bias.

2. Identifying Assumptions

Let $\mathbb{1}_i(n)$ be an indicator function that is equal to one if investor i and issuer n are the same country. Equations (8) and (9) imply that

$$-\log(w_{i,t}(0 \mid l)) = \log\left(1 + \sum_{n=1}^{N} \exp\left(\lambda_l \mu_{i,t}(n,l) + \underbrace{\boldsymbol{\Lambda}_l' \boldsymbol{x}_{i,t}(n) + \epsilon_{i,t}(n,l)}_{\Upsilon_{i,l}\mathbb{1}_i(n)+\upsilon_{i,l}+\eta_{i,t}(n,l)}\right)\right). \tag{30}$$

In this equation, we split the demand shifter into an investor-specific home bias $\Upsilon_{i,l}\mathbb{1}_i(n)+\upsilon_{i,l}$ that is time invariant and the remainder $\eta_{i,t}(n,l)$ that is time varying. To be conservative, we use only the investor-specific home bias for identification, allowing for potential correlation between latent demand within asset class $\epsilon_{i,t}(n,l)$ and across asset classes $\xi_{i,t}(l)$. For example, latent demand could have been low for Greece, Italy, and Portugal during the European sovereign debt crisis, which could have spilled over to a broader loss of confidence in the long-term debt market.

After estimating demand within asset class (16), we have estimates of the demand shifters, which we denote as $\widehat{\boldsymbol{\Lambda}}_l' \boldsymbol{x}_{i,t}(n) + \widehat{\epsilon}_{i,t}(n,l)$. For each investor i and asset class l, we estimate the investor-specific home bias through a regression:

$$\widehat{\boldsymbol{\Lambda}}_l' \boldsymbol{x}_{i,t}(n) + \widehat{\epsilon}_{i,t}(n,l) = \Upsilon_{i,l}\mathbb{1}_i(n) + \upsilon_{i,l} + \eta_{i,t}(n,l). \tag{31}$$

Let

$$\widehat{\delta}_i(n,l) = \exp\left(\widehat{\Upsilon}_{i,l}\mathbb{1}_i(n) + \widehat{\upsilon}_{i,l}\right), \tag{32}$$

where $\widehat{\Upsilon}_{i,l}$ 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

$$\widehat{w}_{i,t}(0 \mid l) = \frac{1}{1 + \sum_{n=1}^{N} \widehat{\delta}_i(n,l)}. \tag{33}$$

The predicted outside portfolio weight is lower for investors with stronger home bias. We estimate equation (29) by instrumental variables, where the three instruments are $-\log(\widehat{w}_{i,t}(0 \mid$

$S)), -\log(\widehat{w}_{i,t}(0 \mid L))$, and $\log(\widehat{w}_{i,t}(0 \mid E))$. The exogeneity condition for identification is

$$\mathbb{E}[\boldsymbol{\xi}_{i,t} \mid \Upsilon_{i,S}, \Upsilon_{i,L}, \Upsilon_{i,E}] = \mathbf{0}. \tag{34}$$

The instruments isolate an inelastic and time-invariant component of the outside portfolio weights due to home bias. In Table 1, Japanese investors own 96 percent of domestic long-term debt, whereas German investors own 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 across investors identifies the asset-class demand elasticities.

3. Estimated Demand

Table 5 reports the estimated coefficients for demand across asset classes. The coefficient on log outside portfolio weight is $\rho_S = 0.30$ for short-term debt, $\rho_L = 0.61$ for long-term debt, and $\rho_E = 0.62$ 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

The aggregate demand elasticity is

$$\begin{aligned} -\frac{\partial \log\left(\sum_{i=1}^{I} Q_{i,t}(n,l)\right)}{\partial p_t(n,l)} =& 1 - \frac{\partial \log\left(\sum_{i=1}^{I} A_{i,t} w_{i,t}(n,l)\right)}{\partial p_t(n,l)} \\ =& 1 - \frac{\sum_{i=1}^{I} A_{i,t}(w_{i,t}(n,l)^2 + \partial w_{i,t}(n,l)/\partial p_t(n,l))}{\sum_{i=1}^{I} A_{i,t} w_{i,t}(n,l)}, \end{aligned} \tag{35}$$

where the second line uses $\partial A_{i,t}/\partial p_t(n,l) = A_{i,t} w_{i,t}(n,l)$. We use the estimated demand system to numerically compute the aggregate demand elasticities. Averaging across years and issuer countries, we compute the mean demand elasticity by asset class and its standard error by the delta method. The mean demand elasticities are 27.9 (1.9) for short-term debt, 3.2 (0.4) for long-term debt, and 1.2 (1.1) 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, Fu, and Li 2023), and US stocks (Chang, Hong, and Liskovich 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 (4). 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. That is, 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. Explaining Exchange Rates and Asset Prices

Based on the estimated demand system, 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 asset demand system defines equilibrium exchange rates and asset prices as a function (15) of the state variables. Exchange rates and asset prices can change from one year to the next only if the state variables change. We develop a variance decomposition that attributes every movement in exchange rates and asset prices to changes in three groups of variables.

First, we change the asset quantities from $\boldsymbol{Q}_t$ to $\boldsymbol{Q}_{t+1}$. We offset this change in world liabilities by a corresponding change in world assets through portfolio flows in year $t+1$ (13). 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 model of short-term rates, the portfolio weights within asset classes, and the aggregate portfolio weights across asset classes. 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 we describe in Appendix D.

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

$$\Delta \boldsymbol{e}_{t+1} = (\boldsymbol{e}(\boldsymbol{Q}_{t+1}) - \boldsymbol{e}_t) + (\boldsymbol{e}(\boldsymbol{X}_{t+1}) - \boldsymbol{e}(\boldsymbol{Q}_{t+1})) + (\boldsymbol{e}_{t+1} - \boldsymbol{e}(\boldsymbol{X}_{t+1})). \tag{36}$$

This equation implies a variance decomposition of exchange rate growth:

$$\begin{aligned} 1 =& \frac{\operatorname{Cov}(\boldsymbol{e}(\boldsymbol{Q}_{t+1}) - \boldsymbol{e}_t, \Delta \boldsymbol{e}_{t+1})}{\operatorname{Var}(\Delta \boldsymbol{e}_{t+1})} + \frac{\operatorname{Cov}(\boldsymbol{e}(\boldsymbol{X}_{t+1}) - \boldsymbol{e}(\boldsymbol{Q}_{t+1}), \Delta \boldsymbol{e}_{t+1})}{\operatorname{Var}(\Delta \boldsymbol{e}_{t+1})} \\ &+ \frac{\operatorname{Cov}(\boldsymbol{e}_{t+1} - \boldsymbol{e}(\boldsymbol{X}_{t+1}), \Delta \boldsymbol{e}_{t+1})}{\operatorname{Var}(\Delta \boldsymbol{e}_{t+1})}. \end{aligned} \tag{37}$$

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

The variance decomposition quantifies causal effects only under a strong assumption that all state variables in equation (15) are exogenous. Otherwise, the variance decomposition generates informative moments to test and to help design international macro models. It is in the same spirit as a variance decomposition of stock returns, based on a present-value identity and a vector autoregression of stock price and cash flow dynamics (Campbell 1991; Vuolteenaho 2002).

B. Estimated Variance 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 2 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 82 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 21 percent, and Pacific investors explain 22 percent. These investor groups naturally represent the largest investors in Table 2.

By construction, the variance decomposition explains all movements in exchange rates through portfolio flows and shifts in asset demand through macro variables and latent demand. Thus, our interpretation of the exchange rate disconnect (Meese and Rogoff 1983) is that shifts in asset demand through macro variables explain much less variation than portfolio flows and shifts in latent demand. Our finding on the importance of latent demand, particularly of North American investors, is consistent with the recent literature that finds explanatory power with variables that capture US demand for foreign assets or the special demand for US assets, especially after the global financial crisis (Camanho, Hau, and Rey 2022; Lilley et al. 2022; Engel and Wu 2023).

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 54 percent of the variation in long-term yields with a standard error of 18 percent. The macro variables explain an additional 43 percent of the variation in long-term yields with a standard error of 10 percent. Latent demand explains a statistically insignificant 3 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 19 percent of the variation in log market-to-book equity with a standard error of 7 percent. The macro variables explain an additional 21 percent of the variation in log market-to-book equity with a standard error of 3 percent. Latent demand explains the remaining 60 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 13 percent, European investors explain 26 percent, Pacific investors explain 9 percent, and emerging market investors explain 12 percent.

C. 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 46 percent, and latent demand explains 32 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 115 percent of the variation in the Italian long-term yield and 74 percent of the variation in the Portuguese long-term yield. When we further decompose latent demand by investor group, European investors alone explain 98 percent of the variation in the Italian long-term yield and 65 percent of the variation in the Portuguese long-term yield.

Figure 6 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. Special Status of 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, Krishnamurthy, and Lustig 2021). In Table 4, the specification for demand within asset class includes expected returns and measures of risk exposure and asset market size. Thus, the asset characteristics already capture the high foreign demand for US assets because of their low risk exposure and large market size. Nevertheless, foreign investors could have special demand for US assets beyond the asset 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. That is, the foreign demand for US equity is 100 percent higher than the average demand for foreign equity, controlling for the asset 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, declining after the European sovereign debt crisis. Overall, US assets appear to be more special than euro-area assets.

B. *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. Our estimates of expected returns are the predicted values from the predictive regressions in Table 3, based on the counterfactual asset prices and exchange rates.

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 (i.e., long non-US dollar currencies) earns a lower expected return in US dollars. In Table 10, a value-weighted exchange rate in US dollars per local currency unit is 5.23 percent higher. Consequently, the expected annual return on a value-weighted portfolio of foreign short-term debt is 1.41 percent lower. We interpret this estimate as a convenience yield of 1.41 percent on the US dollar. We decompose this convenience yield by investor group and find that the most important sources are 0.92 percent from foreign exchange reserves, 0.23 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 0.73 percent higher, and the expected annual return is 2.71 percent higher. We decompose this convenience yield by investor group and find that the most important sources are 1.03 percent from foreign exchange reserves, 0.80 percent from European investors, and 0.73 percent from Pacific investors. Figure 7 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 3.35 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.

We make two important qualifications regarding our estimates of convenience yields. First, our estimates are upward biased if there are omitted characteristics in our specification of asset demand that further explain the high demand for US assets. Second, we assume that the supply of US assets does not change in the absence of special demand for US assets. Choi, Kirpalani, and Perez (2024) argue that the US government has market power and develop a model with endogenous supply of US Treasury debt.

VII. Conclusion

We develop an asset demand system to analyze the equilibrium relation between international portfolio holdings and flows, exchange rates, short-term rates, long-term yields, and equity prices across all countries. We introduce a nested logit model of asset demand with substitution across countries in the inner nest and across asset classes in the outer nest. We develop a new identification strategy to estimate the nested logit model of asset demand by instrumental variables. We estimate the asset demand system on international portfolio holdings data across 37 countries and three asset classes from 2003 to 2020. We use the estimated demand system 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 yields on US assets. In units of expected annual returns, the mean convenience yield is 1.41 percent on the US dollar, 2.71 percent on US long-term debt, and 0.50 percent on US equity.

Recent work on international macro models emphasizes inelastic demand and asset demand shocks unrelated to fundamentals to resolve longstanding puzzles in international finance (Blanchard, Giavazzi, and Sa 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 and to help design international macro models. We estimate mean demand elasticities of 27.9 (1.9) for short-term debt, 3.2 (0.4) for long-term debt, and 1.2 (1.1) for equity with the standard errors in parentheses. We also find that latent demand explains 82 percent of the variation in exchange rates, 86 percent of the variation in short-term rates, 3 percent of the variation in long-term yields, and 60 percent of the variation in log market-to-book equity.

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 research could use the demand system approach to explain and to predict the impact of monetary policy on exchange rates and asset prices (Koijen et al. 2021; Darmouni, Siani, and Xiao 2022).

Data Availability

Data and code for this research are available from Koijen and Yogo (2025) in the Harvard Dataverse, https://doi.org/10.7910/DVN/9KNRFO. They were checked by the Journal for their ability to reproduce the results presented in the paper. The authors were granted an exemption to publish parts of their data because access to these data is restricted. However, the authors provided the Journal with temporary access to the parts with restricted data, which enabled the Journal to check reproducibility of results. Code for all parts of the paper and unrestricted data are available in the above deposit.

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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

Note.—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

Note.—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

Note.—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

Note.—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, Table 5.2). 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	0.30
		(0.03)
Long-term debt	ρ_L	0.61
		(0.06)
Equity	ρ_E	0.62
		(0.04)
Indicator variables:		
Short-term debt	α_S	-0.82
		(0.20)
Long-term debt	α_L	1.13
		(0.22)
F-statistic for weak IV		404
Observations		1,352

Note.—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

Note.—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	0.02		0.54	0.19
	(0.05)		(0.18)	(0.07)
Macro variables	0.16	0.14	0.43	0.21
	(0.06)	(0.06)	(0.10)	(0.03)
Latent demand	0.82	0.86	0.03	0.60
	(0.07)	(0.06)	(0.26)	(0.07)
Reserves	0.10		0.02	-0.01
	(0.01)		(0.03)	(0.01)
North America	0.32	0.45	-0.21	0.13
	(0.09)	(0.14)	(0.19)	(0.07)
Europe	0.21	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	0.09	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

Note.—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	0.22	0.14	0.24
	(0.11)	(0.17)	(0.04)
Macro variables	0.46	-0.28	0.02
	(0.09)	(0.17)	(0.19)
Latent demand	0.32	1.15	0.74
	(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	0.98	0.65
	(0.01)	(0.19)	(0.16)
Pacific	0.02	0.05	0.05
	(0.00)	(0.02)	(0.01)
Emerging markets	0.08	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

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

Table 9
Mean Latent Demand

Year	United States Short-term debt	United States Long-term debt	United States Equity	Euro area Short-term debt	Euro area Long-term debt	Euro area 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

Note.—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 Yield on US Assets

Investor	Foreign short-term debt: Exchange rate	Foreign short-term debt: Expected return	US long-term debt: Yield	US long-term debt: Expected return	US equity: Market-to-book	US equity: Expected return
Total	5.23	-1.41	0.73	2.71	-3.35	0.50
	(0.56)	(0.15)	(0.09)	(0.35)	(0.39)	(0.06)
Reserves	3.41	-0.92	0.28	1.03	-0.08	0.01
	(0.43)	(0.12)	(0.03)	(0.13)	(0.02)	(0.00)
North America	0.06	-0.02	0.01	0.05	-0.37	0.05
	(0.01)	(0.00)	(0.00)	(0.00)	(0.04)	(0.01)
Europe	0.84	-0.23	0.21	0.80	-1.75	0.26
	(0.09)	(0.02)	(0.03)	(0.11)	(0.20)	(0.03)
Pacific	0.52	-0.14	0.20	0.73	-0.87	0.13
	(0.07)	(0.02)	(0.03)	(0.10)	(0.10)	(0.01)
Emerging markets	0.13	-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)

Note.—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, based on the counterfactual asset prices and exchange rates. Heteroskedasticity-robust standard errors are reported in parentheses. The annual sample period is 2003 to 2020.

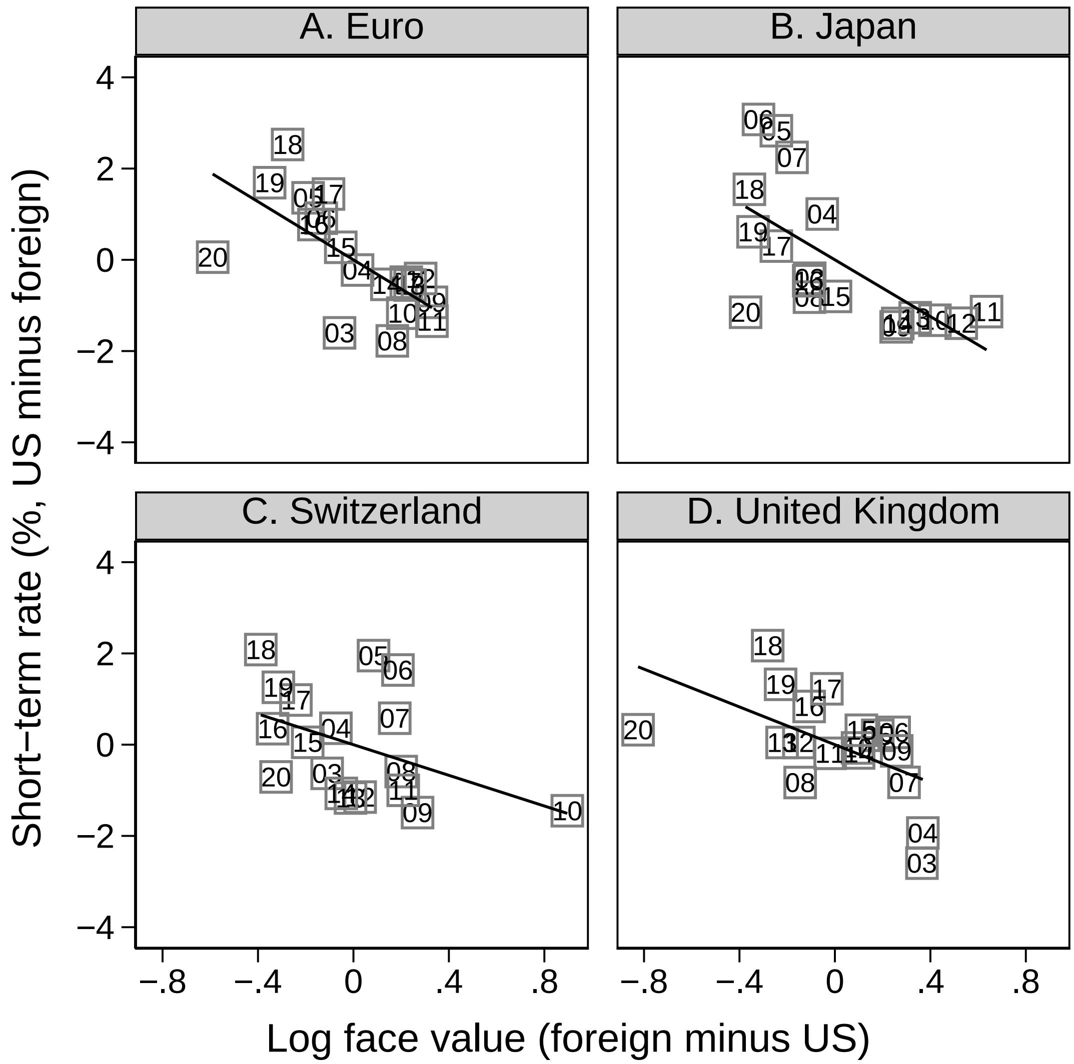

Figure 1. Relative short-term debt prices versus quantities. The vertical axis is the US short-term rate minus each region's short-term rate, reported in annual percentage points. The horizontal axis is each region's log face value of short-term debt in US dollars minus log face value of US short-term 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.

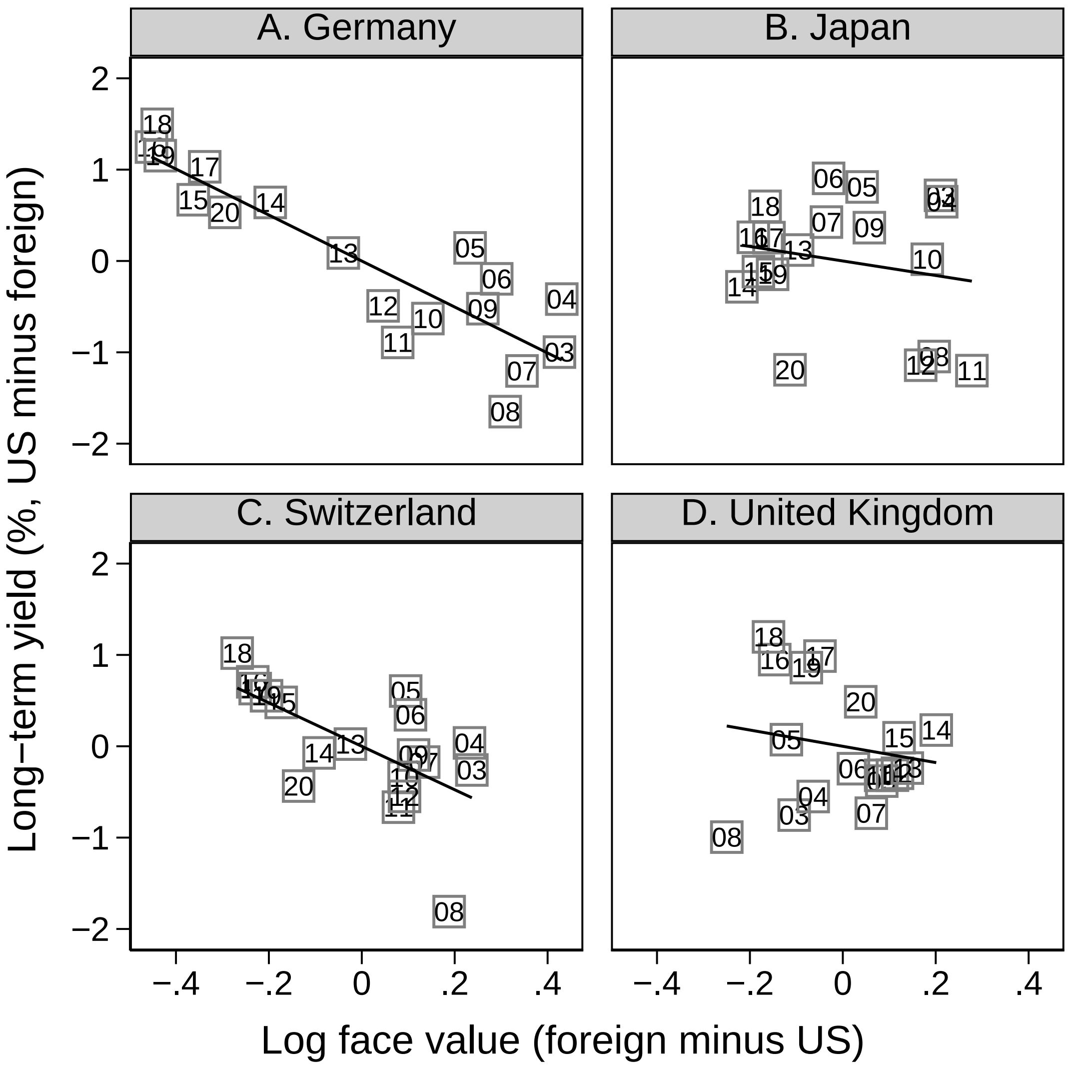

Figure 2. Relative long-term debt prices versus quantities. The vertical axis is the US long-term yield minus each country's long-term yield, reported in annual percentage points. The horizontal axis is each country's log face value of long-term debt in US dollars minus log face value of US long-term 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.

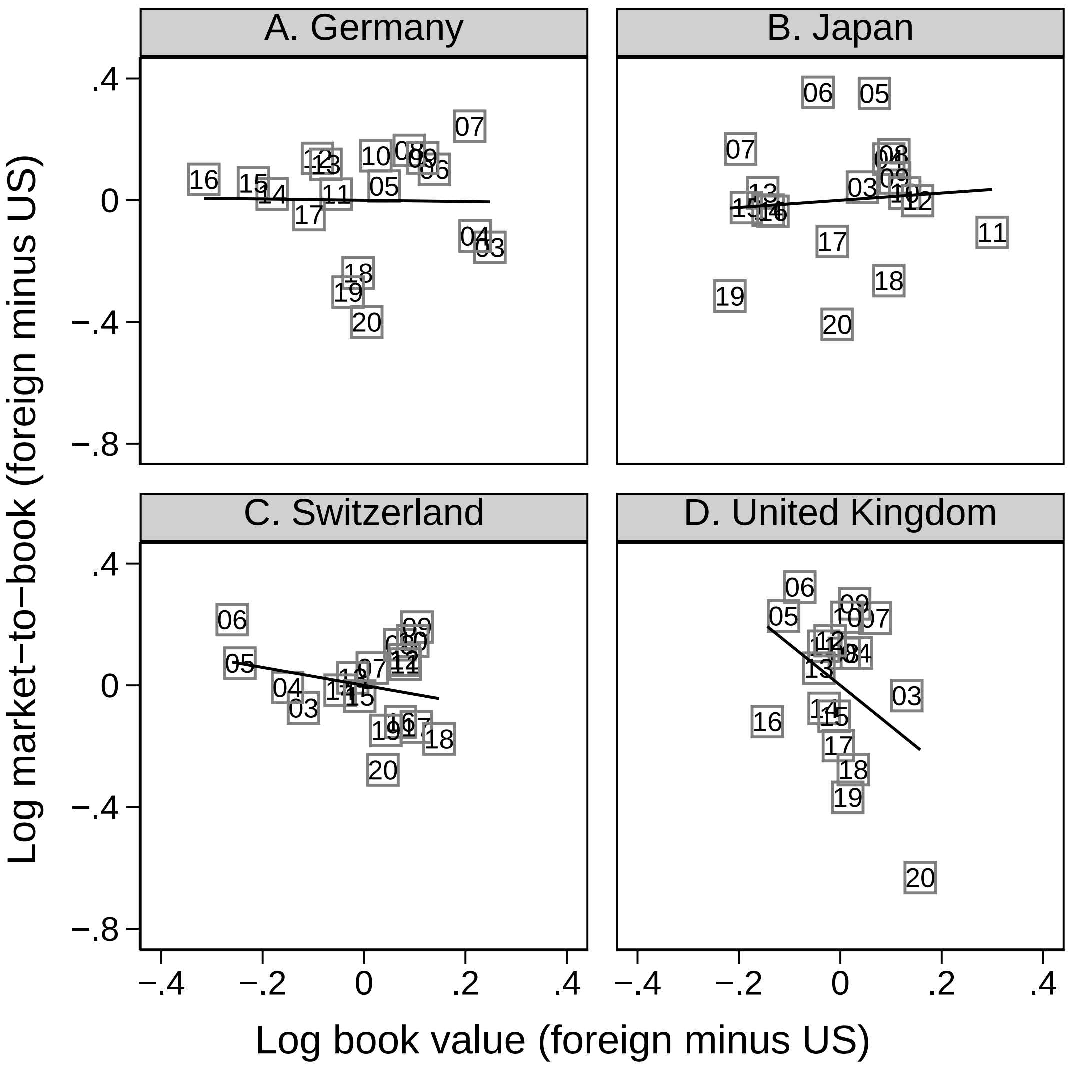

Figure 3. Relative equity prices versus quantities. The vertical axis is each country's log market-to-book equity minus the US log market-to-book equity. The horizontal axis is each country's log book equity in US dollars minus the US log book equity. Each axis is demeaned by the time-series mean. The two-digit number represents year (e.g., 03 is 2003). Each panel shows the linear regression line.

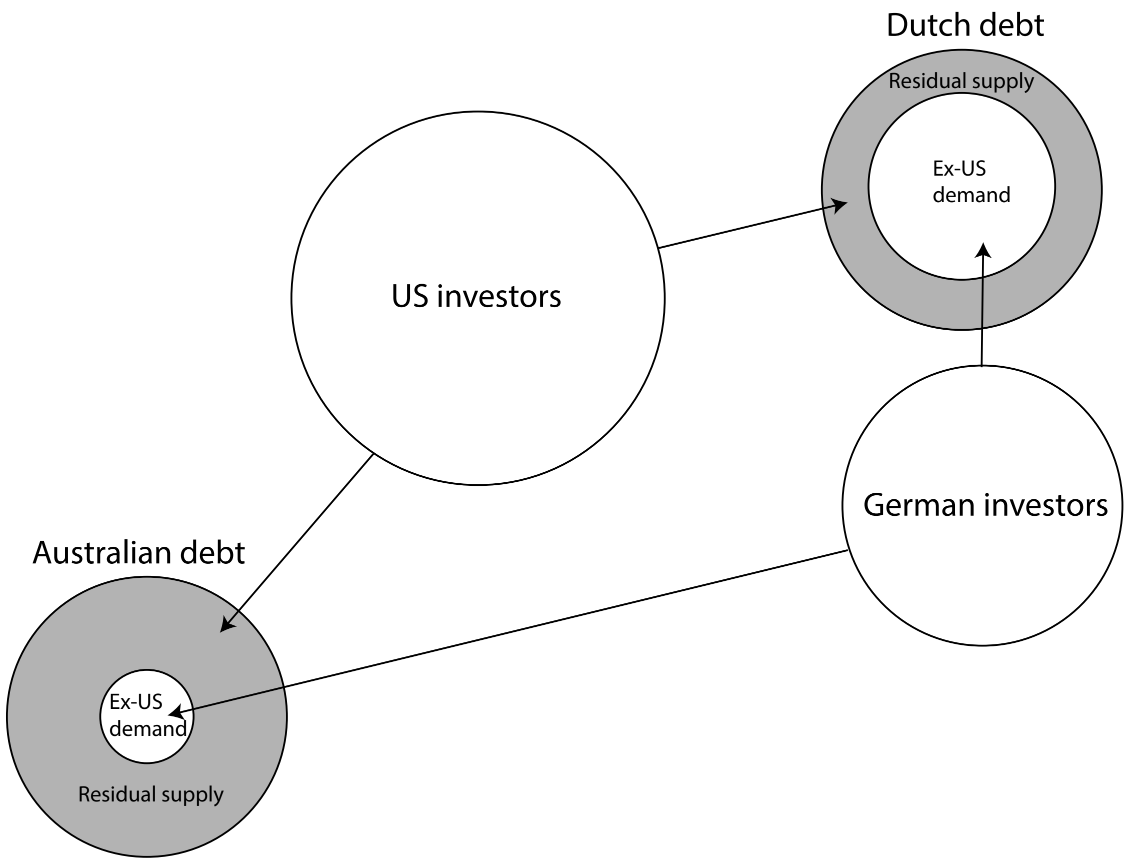

Figure 4. Illustration of residual supply. This figure illustrates the residual supply of Dutch and Australian debt from the perspective of US investors. German investors have a higher demand for Dutch than Australian debt through a gravity effect that depends on the bilateral distance between countries.

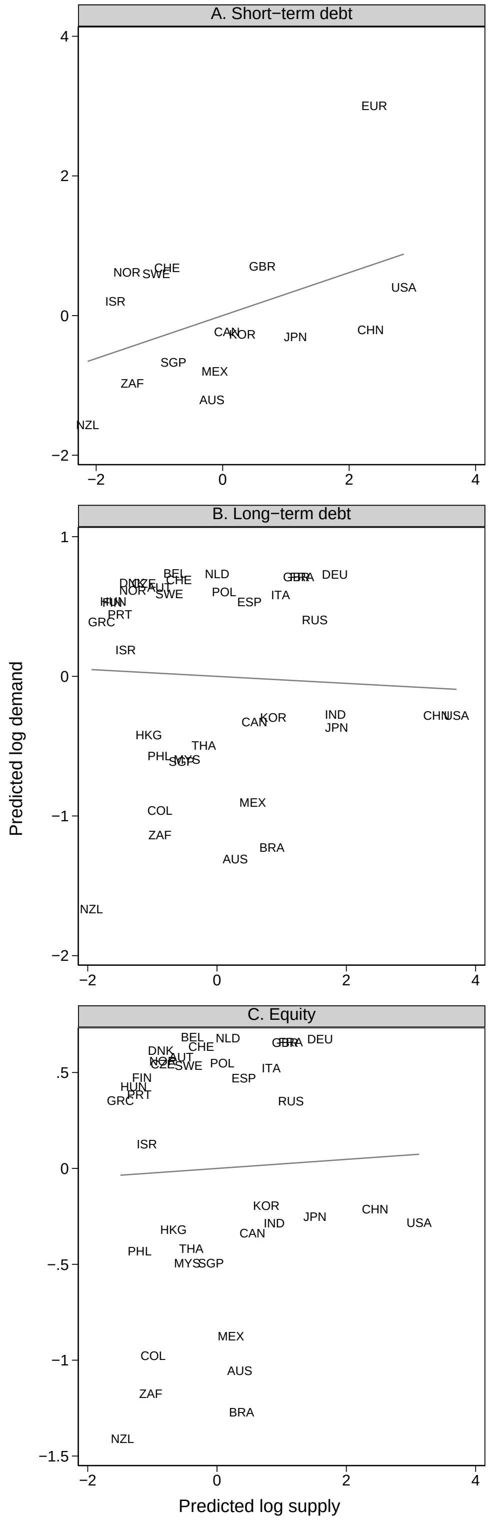

Figure 5. Constructing instrumental variables. Each panel reports the predicted log demand and the predicted log supply from the perspective of US investors in 2020. The predicted log demand is the predicted value of a panel regression of log portfolio weights on the bilateral distance, aggregated across other investors. The predicted log supply is the predicted value of a panel regression of log asset quantity on log GDP and log population.

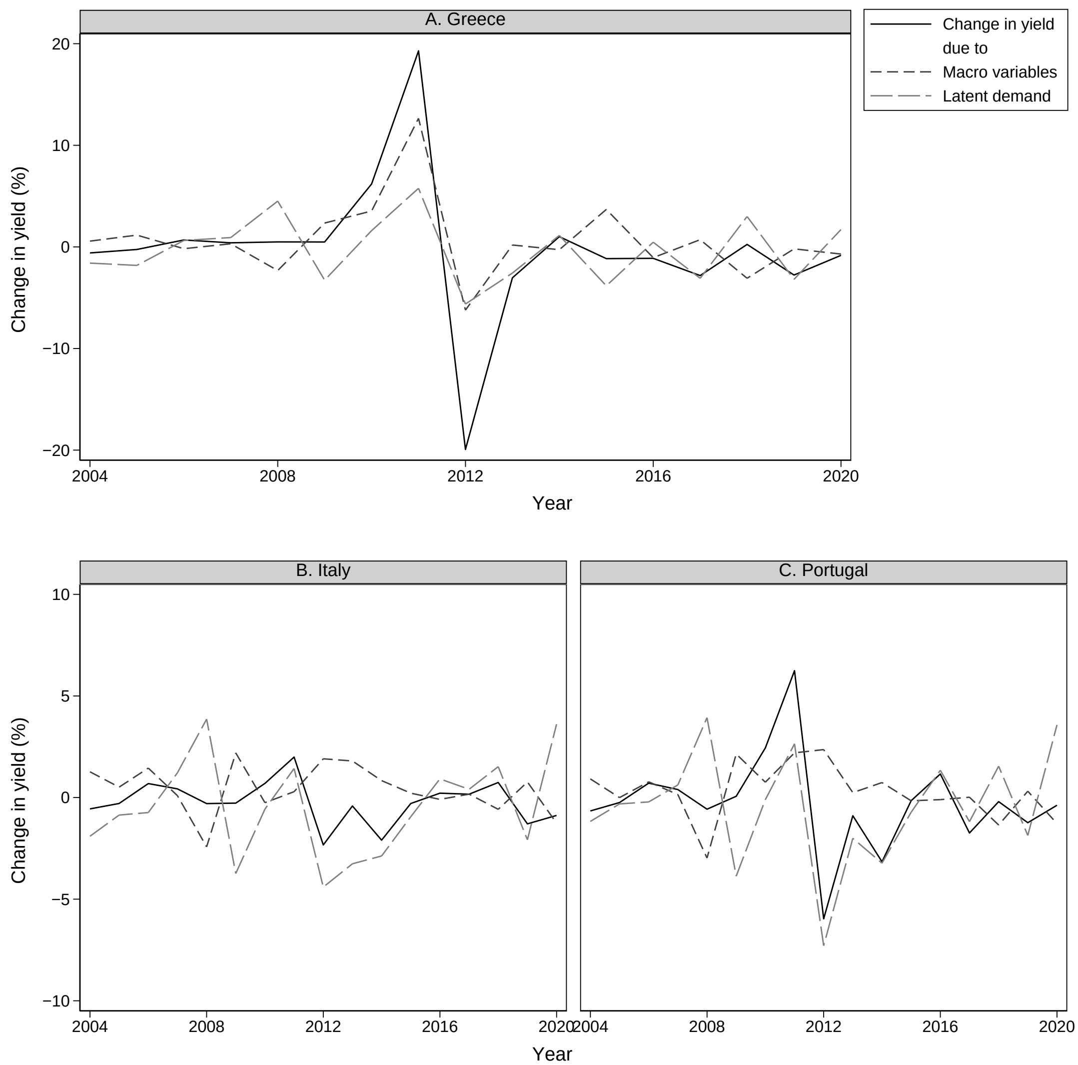

Figure 6. Long-term yields in the euro area. Annual changes in the long-term yields are decomposed into portfolio flows and shifts in asset demand through macro variables and latent demand. This figure reports the changes due to the macro variables and latent demand only.

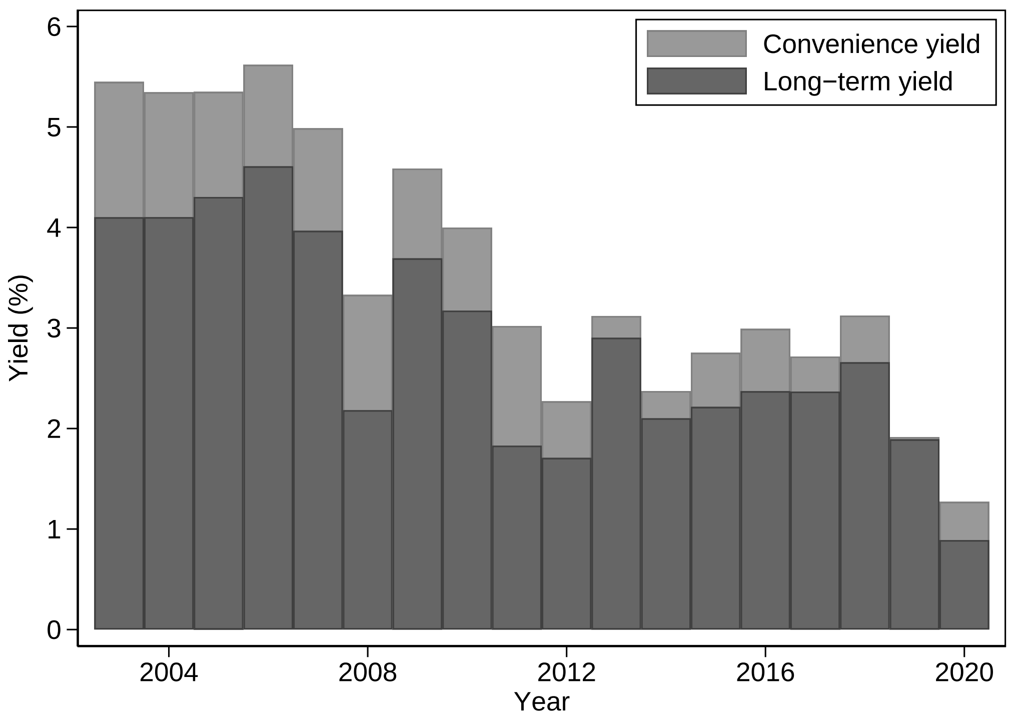

Figure 7. Convenience yield on US long-term debt. This figure reports the change in the long-term yield in the absence of special demand for US long-term debt, reported in annual percentage points. Special demand is estimated as the cross-sectional mean of latent demand for US long-term debt by year, excluding the US investors' latent demand.

Appendix A. Two-Country Model

We start with a general equilibrium model of an endowment economy with two periods, two countries, and two assets (Lucas 1982). The two countries are the United States and Japan with a representative investor in each country. We solve for the optimal consumption and portfolio choice of US and Japanese investors. The four optimality equations and market clearing of the two consumption goods and the two assets determine the equilibrium exchange rate and asset prices.

We use the general equilibrium model as a microfoundation to help design an asset demand system. We replace the consumption Euler equations with a model of interest rates. Since the optimal portfolios in a traditional model do not explain features such as the gravity effect and home bias, we replace them with asset demand functions. Finally, we introduce a model of wealth with exogenous portfolio flows. The model of interest rates, the asset demand functions, the model of wealth, and market clearing of the two assets determine the equilibrium exchange rate and asset prices. We relate our modeling approach to the portfolio balance models (Kouri 1983; Blanchard, Giavazzi, and Sa 2005) and Hau and Rey (2006).

A. *Endowments, Consumption, and Price Indices*

At time t, US investors receive an endowment $Y_{U,t}$ of a consumption good, and Japanese investors receive an endowment $Y_{J,t}$ of a different consumption good. US and Japanese investors have preferences for consumption variety and trade subject to trade costs.[4] Investor i consumes $C_{i,t}(i)$ units of the domestic good at price $B_{i,t}(i) = 1$ and $C_{i,t}(n)$ units of the foreign good at price $B_{i,t}(n)$. Both good prices are in local currency, and we normalize the domestic good price to one.

The investor's consumption index is a constant elasticity of substitution (CES) aggregator over domestic and foreign goods:

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

where $\phi > 0$ is the elasticity of substitution. Utility maximization implies that the total consumption expenditure is

$$B_{i,t}C_{i,t} = C_{i,t}(i) + B_{i,t}(n)C_{i,t}(n), \tag{A2}$$

[4]Various microfoundations lead to a home bias for domestic goods including trade costs, direct preferences for domestic goods, 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.

where the consumer price index is

$$B_{i,t} = \left(1 + B_{i,t}(n)^{1-\phi}\right)^{\frac{1}{1-\phi}}. \tag{A3}$$

If the US consumer price index is $B_{U,t}$ dollars and the Japanese consumer price index is $B_{J,t}$ yen, $V_t = B_{U,t}/B_{J,t}$ 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.

We assume the presence of iceberg trade costs such that $\tau_{i,t}(n) \geq 1$ units of country n's good become one unit of country i's consumption. The law of one price implies that $B_{U,t}(J) = \tau_{U,t}(J)E_t$ and $B_{J,t}(U) = \tau_{J,t}(U)/E_t$. Substituting these good prices in equation (A3), the US and Japanese consumer price indices are

$$B_{U,t} = \left(1 + (\tau_{U,t}(J)E_t)^{1-\phi}\right)^{\frac{1}{1-\phi}}, \tag{A4}$$

$$B_{J,t} = \left(1 + \left(\frac{\tau_{J,t}(U)}{E_t}\right)^{1-\phi}\right)^{\frac{1}{1-\phi}}. \tag{A5}$$

That is, the exchange rate and trade costs fully determine the consumer price indices.

Let $\boldsymbol{X}_t$ be an exogenous state vector at time t, which contains all relevant information for the distribution of endowment income at time $t+1$. The endowment income is conditionally lognormal:

$$\Delta \boldsymbol{y}_{t+1} \sim \mathbb{N}(\boldsymbol{\mu}(\boldsymbol{X}_t), \boldsymbol{\Sigma}(\boldsymbol{X}_t)). \tag{A6}$$

B. Asset Markets

Each country has a real bond that is indexed to its consumer price index. The US bond has price $P_t(U)$ dollars at time t and a payoff $B_{U,t+1}/B_{U,t}$ dollars at time $t+1$. We denote its gross real return in dollars as $R_{t+1}(U) = 1/P_t(U)$. The Japanese bond has price $P_t(J)$ yen at time t and a payoff $B_{J,t+1}/B_{J,t}$ yen at time $t+1$. We denote its gross real return in yen as $R_{t+1}(J) = 1/P_t(J)$. Our modeling assumption of real rather than nominal bonds simplifies the exposition as we describe below.

C. Investors and Governments

1. US Investors

At time t, US investors receive an endowment of $Y_{U,t}$ dollars and consume $B_{U,t}C_{U,t}$ dollars. Their wealth after consumption in dollars is

$$A_{U,t} = \underbrace{Y_{U,t} - B_{U,t}C_{U,t}}_{F_{U,t}}. \tag{A7}$$

We refer to $F_{U,t}$ as the portfolio flow in the asset demand system that we develop. They allocate a share $w_{U,t}(J)$ of their wealth to Japanese bonds and the remaining share to US bonds. Their gross real portfolio return is

$$R_{U,t+1} = R_{t+1}(U) + w_{U,t}(J)\left(\frac{R_{t+1}(J)E_{t+1}/V_{t+1}}{E_t/V_t} - R_{t+1}(U)\right) \tag{A8}$$

in dollars from time t to $t+1$. They receive another endowment of $Y_{U,t+1}$ dollars, pay a lumpsum tax of $T_{U,t+1}$ units of consumption, and consume their remaining wealth at time $t+1$. Therefore, their intertemporal budget constraint is

$$C_{U,t+1} = R_{U,t+1}\frac{A_{U,t}}{B_{U,t}} + \frac{Y_{U,t+1}}{B_{U,t+1}} - T_{U,t+1}. \tag{A9}$$

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. They solve a consumption and portfolio choice problem at time t:

$$\max_{C_{U,t},w_{U,t}(J)} \frac{C_{U,t}^{1-\gamma}}{1-\gamma} + \beta\frac{\mathbb{E}_t\left[C_{U,t+1}^{1-\gamma}\right]}{1-\gamma}, \tag{A10}$$

subject to the intertemporal budget constraint (A9).

2. Japanese Investors

At time t, Japanese investors receive an endowment of $Y_{J,t}$ yen and consume $B_{J,t}C_{J,t}$ yen. Their wealth after consumption in dollars is

$$A_{J,t} = E_t(\underbrace{Y_{J,t} - B_{J,t}C_{J,t}}_{F_{J,t}}). \tag{A11}$$

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

$$R_{J,t+1} = R_{t+1}(J) + w_{J,t}(U)\left(\frac{R_{t+1}(U)E_t/V_t}{E_{t+1}/V_{t+1}} - R_{t+1}(J)\right) \tag{A12}$$

in yen from time t to $t+1$. They receive another endowment of $Y_{J,t+1}$ yen, pay a lumpsum tax of $T_{J,t+1}$ units of consumption, and consume their remaining wealth at time $t+1$. Therefore, their intertemporal budget constraint is

$$C_{J,t+1} = R_{J,t+1}\frac{A_{J,t}}{E_t B_{J,t}} + \frac{Y_{J,t+1}}{B_{J,t+1}} - T_{J,t+1}. \tag{A13}$$

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 (A10) with the subscript J instead of U), subject to the intertemporal budget constraint (A13).

3. Governments

We model US and Japanese governments separately from investors to define an exogenous supply of US and Japanese bonds. The government in country n inelastically issues real debt, indexed to its consumer price index, with face value $Q_t(n)$ at time t. Thus, the quantity of debt $Q_t(n)$ is exogenous, but its price $P_t(n)$ is endogenous.

At time t, the government in country n consumes $G_{n,t}(n)$ units of the domestic good at price $B_{n,t}(n) = 1$ and $G_{n,t}(m)$ units of the foreign good at price $B_{n,t}(m)$. The debt finances total government expenditure of

$$P_t(n)Q_t(n) = G_{n,t}(n) + B_{n,t}(m)G_{n,t}(m) = B_{n,t}G_{n,t}, \tag{A14}$$

where

$$G_{n,t} = \left(G_{n,t}(n)^{1-1/\phi} + G_{n,t}(m)^{1-1/\phi}\right)^{\frac{1}{1-1/\phi}}. \tag{A15}$$

To satisfy its intertemporal budget constraint (i.e., $T_{n,t+1} = R_{t+1}(n)G_{n,t}$), the government collects a lumpsum tax of $T_{n,t+1} = Q_t(n)/B_{n,t}$ units of consumption from its domestic investors at time $t+1$.

D. Market Clearing

Market clearing of US and Japanese goods at time t are

$$Y_{U,t} = C_{U,t}(U) + G_{U,t}(U) + \tau_{J,t}(U)(C_{J,t}(U) + G_{J,t}(U)), \tag{A16}$$
$$Y_{J,t} = C_{J,t}(J) + G_{J,t}(J) + \tau_{U,t}(J)(C_{U,t}(J) + G_{U,t}(J)). \tag{A17}$$

Using standard properties of the CES aggregator, we rewrite these equations as

$$Y_{U,t} = B_{U,t}^{\phi}(C_{U,t} + G_{U,t}) + \tau_{J,t}(U)^{1-\phi}(E_t B_{J,t})^{\phi}(C_{J,t} + G_{J,t}), \tag{A18}$$
$$E_t Y_{J,t} = E_t B_{J,t}^{\phi}(C_{J,t} + G_{J,t}) + (\tau_{U,t}(J) E_t)^{1-\phi} B_{U,t}^{\phi}(C_{U,t} + G_{U,t}). \tag{A19}$$

Endowment income in dollars equals total consumption and government expenditures for each good.

Market clearing of US and Japanese bonds at time t are

$$P_t(U) Q_t(U) = A_{U,t}(1 - w_{U,t}(J)) + A_{J,t} w_{J,t}(U), \tag{A20}$$
$$E_t P_t(J) Q_t(J) = A_{U,t} w_{U,t}(J) + A_{J,t}(1 - w_{J,t}(U)). \tag{A21}$$

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.

Market clearing of US and Japanese goods at time $t+1$ are

$$Y_{U,t+1} = B_{U,t+1}^{\phi} C_{U,t+1} + \tau_{J,t+1}(U)^{1-\phi}(E_{t+1} B_{J,t+1})^{\phi} C_{J,t+1}, \tag{A22}$$
$$E_{t+1} Y_{J,t+1} = E_{t+1} B_{J,t+1}^{\phi} C_{J,t+1} + (\tau_{U,t+1}(J) E_{t+1})^{1-\phi} B_{U,t+1}^{\phi} C_{U,t+1}. \tag{A23}$$

following the same derivation as equations (A18) and (A19). Endowment income in dollars equals total consumption expenditures for each good.

E. Optimal Consumption and Portfolio Choice

For US investors, the first-order conditions for consumption and portfolio choice are

$$\mathbb{E}_t \left[\beta \left(\frac{C_{U,t+1}}{C_{U,t}} \right)^{-\gamma} R_{t+1}(U) \right] = 1, \tag{A24}$$
$$\mathbb{E}_t \left[\beta \left(\frac{C_{U,t+1}}{C_{U,t}} \right)^{-\gamma} \frac{R_{t+1}(J) E_{t+1}/V_{t+1}}{E_t/V_t} \right] = 1. \tag{A25}$$

For Japanese investors, the first-order conditions for consumption and portfolio choice are

$$\mathbb{E}_t\left[\beta\left(\frac{C_{J,t+1}}{C_{J,t}}\right)^{-\gamma}R_{t+1}(J)\right]=1, \tag{A26}$$

$$\mathbb{E}_t\left[\beta\left(\frac{C_{J,t+1}}{C_{J,t}}\right)^{-\gamma}\frac{R_{t+1}(U)E_t/V_t}{E_{t+1}/V_{t+1}}\right]=1. \tag{A27}$$

Equations (A24) and (A26) imply that

$$\begin{aligned}1 =&\mathbb{E}_t[\exp(\log(\beta)-\gamma\Delta c_{n,t+1}+r_{t+1}(n))] \qquad \text{(A28)}\\ \approx&\exp\left(\log(\beta)-\gamma\mathbb{E}_t[\Delta c_{n,t+1}]+\frac{\gamma^2\mathrm{Var}_t(\Delta c_{n,t+1})}{2}+r_{t+1}(n)\right),\end{aligned}$$

where $n=U$ for US investors and $n=J$ for Japanese investors. Taking logarithms of both sides and rearranging, we have a pair of linearized Euler equations:

$$r_{t+1}(n)=-p_t(n)=-\log(\beta)+\gamma\mathbb{E}_t[\Delta c_{n,t+1}]-\frac{\gamma^2\mathrm{Var}_t(\Delta c_{n,t+1})}{2}. \tag{A29}$$

The real bond return increases in expected consumption growth due to intertemporal substitution and decreases in the variance of consumption growth due to a precautionary motive.

We also have a pair of optimal portfolio weights for US and Japanese investors. For US investors, we denote the conditional mean, variance, and covariance of the Japanese bond return as

$$\mu_{U,t}(J)=\mathbb{E}_t[r_{t+1}(J)+\Delta(e_{t+1}-v_{t+1})-r_{t+1}(U)], \tag{A30}$$

$$\sigma^2_{U,t}(J)=\mathrm{Var}_t(\Delta(e_{t+1}-v_{t+1})), \tag{A31}$$

$$\overline{\sigma}_{U,t}(J)=\mathrm{Cov}_t(y_{U,t+1}-b_{U,t+1},\Delta(e_{t+1}-v_{t+1})). \tag{A32}$$

For Japanese investors, we denote the conditional mean, variance, and covariance of the US bond return as

$$\mu_{J,t}(U)=\mathbb{E}_t[r_{t+1}(U)-\Delta(e_{t+1}-v_{t+1})-r_{t+1}(J)], \tag{A33}$$

$$\sigma^2_{J,t}(U)=\mathrm{Var}_t(-\Delta(e_{t+1}-v_{t+1})), \tag{A34}$$

$$\overline{\sigma}_{J,t}(U)=\mathrm{Cov}_t(y_{J,t+1}-b_{J,t+1},-\Delta(e_{t+1}-v_{t+1})). \tag{A35}$$

The real exchange rate enters with the opposite sign in equations (A30) and (A33) because US investors care about returns in dollars and Japanese investors care about returns in yen.

By Campbell and Viceira (2002, equation 6.11), investor i's optimal portfolio weight on the foreign bond n is

$$w_{i,t}(n) = \kappa \frac{\mu_{i,t}(n) + \sigma_{i,t}^2(n)/2}{\gamma \sigma_{i,t}^2(n)} - (\kappa - 1)\frac{\overline{\sigma}_{i,t}(n)}{\sigma_{i,t}^2(n)}, \tag{A36}$$

where $i = U$ for US investors, $i = J$ for Japanese investors, and $\kappa > 1$ is a constant.

The optimal portfolio (A36) is a weighted sum of the mean-variance portfolio and a hedging portfolio. For US investors, the US bond is riskless, but the Japanese bond is risky because of exchange rate risk. The mean-variance portfolio implies that US investors increase their allocation to the Japanese bond if it has a high expected excess return relative to variance. The hedging portfolio implies that US investors increase their allocation to the Japanese bond if it hedges income risk, by delivering a high return in US dollars when their income is low (Heathcote and Perri 2013). Our modeling assumption of real rather than nominal bonds simplifies equation (A36) by avoiding another term for inflation hedging demand.

F. Equilibrium

At time t, the exogenous state vector $\boldsymbol{X}_t$ includes endowment income $\boldsymbol{y}_t = [y_{U,t}, y_{J,t}]'$ and bond supply $\boldsymbol{q}_t = [q_t(U), q_t(J)]'$. By the budget constraints (A7) and (A11), we can write the consumption policies in terms of wealth rather than consumption, which is more convenient notation for the asset demand system that we develop. Thus, the policy variables are wealth $\boldsymbol{A}_t = [A_{U,t}, A_{J,t}]'$ and portfolio choice $\boldsymbol{w}_t = [w_{U,t}(J), w_{J,t}(U)]'$. The endogenous prices are the exchange rate e_t and bond prices $\boldsymbol{p}_t = [p_t(U), p_t(J)]'$.

1. Equilibrium at Time $t+1$

We write the intertemporal budget constraints for US investors (A9) and Japanese investors (A13) as a two-dimensional vector:

$$\boldsymbol{c}_{t+1} = \boldsymbol{c}(e_{t+1}; \boldsymbol{A}_t, \boldsymbol{w}_t, e_t, \boldsymbol{p}_t; \boldsymbol{q}_t, \boldsymbol{y}_t, \boldsymbol{y}_{t+1}). \tag{A37}$$

We write market clearing of Japanese goods at time $t+1$ (A23) as an implicit function:

$$e_{t+1} = e(\boldsymbol{c}_{t+1}; \boldsymbol{y}_{t+1}). \tag{A38}$$

US goods also clear by Walras's law. The solution to this system of three equations is

$$[\boldsymbol{c}'_{t+1}, e_{t+1}]' = \boldsymbol{m}_{t+1}(\boldsymbol{A}_t, \boldsymbol{w}_t, e_t, \boldsymbol{p}_t; \boldsymbol{q}_t, \boldsymbol{y}_t, \boldsymbol{y}_{t+1}). \tag{A39}$$

2. Equilibrium at Time t

Optimal consumption (A29) and portfolio choice (A36) depend on the conditional mean and variance of a vector of endogenous variables:

$$\boldsymbol{n}_{t+1} = [\Delta \boldsymbol{c}'_{t+1}, \Delta(e_{t+1} - v_{t+1}), (\boldsymbol{y}_{t+1} - \boldsymbol{b}_{t+1})']'. \tag{A40}$$

Given the distribution of endowment income (A6) and the solution at time $t+1$ (A39), we compute the conditional moments of the endogenous variables (A40) as

$$\mathbb{E}_t[\boldsymbol{n}_{t+1}] = \boldsymbol{\mu}(\boldsymbol{A}_t, \boldsymbol{w}_t, e_t, \boldsymbol{p}_t; \boldsymbol{X}_t), \tag{A41}$$

$$\operatorname{Var}_t(\boldsymbol{n}_{t+1}) = \boldsymbol{\Sigma}(\boldsymbol{A}_t, \boldsymbol{w}_t, e_t, \boldsymbol{p}_t; \boldsymbol{X}_t). \tag{A42}$$

Substituting the conditional moments (A41) and (A42), we write optimal consumption (A29) and portfolio choice (A36) of US and Japanese investors at time t as a four-dimensional implicit function:

$$[\boldsymbol{A}'_t, \boldsymbol{w}'_t]' = \boldsymbol{m}_{c,w}(e_t, \boldsymbol{p}_t; \boldsymbol{X}_t). \tag{A43}$$

We write market clearing of Japanese goods (A19), US bonds (A20), and Japanese bonds (A21) at time t as a three-dimensional implicit function:

$$[e_t, \boldsymbol{p}'_t]' = \boldsymbol{m}_{e,p}(\boldsymbol{A}_t, \boldsymbol{w}_t; \boldsymbol{q}_t, \boldsymbol{y}_t). \tag{A44}$$

US goods also clear by Walras's law. The solution to this system of seven equations is

$$[\boldsymbol{A}'_t, \boldsymbol{w}'_t, e_t, \boldsymbol{p}'_t]' = \boldsymbol{m}_t(\boldsymbol{X}_t). \tag{A45}$$

G. Asset Demand System

We develop an asset demand system by making additional assumptions about the conditional moments (A41) and (A42). The purpose of these assumptions is to replace the consumption Euler equations with a model of interest rates and the optimal portfolios with asset demand functions.

1. Distributional Assumptions

The following proposition justifies our approach of making direct assumptions about the conditional moments of the endogenous variables. It shows that we can reverse engineer a distribution of endowment income (A6) that delivers a given set of conditional moments (A41) and (A42).

PROPOSITION 1. Specify the conditional moments (A41) and (A42) as functions of the endogenous variables and the exogenous state vector $\boldsymbol{X}_t$. There exists a distribution of endowment income (A6) that implies the specified conditional moments, up to a first-order Taylor approximation of $\boldsymbol{n}_{t+1} = \boldsymbol{n}(\boldsymbol{X}_t, \boldsymbol{y}_{t+1})$ around $\boldsymbol{y}_{t+1} \approx \boldsymbol{y}_t$.

Proof. Using the equilibrium equations at time $t+1$ (A39) and time t (A45), we write the vector of endogenous variables (A40) as a function of $\boldsymbol{X}_t$ and the endowment income at time $t+1$:

$$\boldsymbol{n}_{t+1} = \boldsymbol{n}(\boldsymbol{X}_t, \boldsymbol{y}_{t+1}). \tag{A46}$$

A first-order Taylor approximation around $\boldsymbol{y}_{t+1} \approx \boldsymbol{y}_t$ implies that

$$\boldsymbol{n}_{t+1} \approx \boldsymbol{n}(\boldsymbol{X}_t, \boldsymbol{y}_t) + \frac{\partial \boldsymbol{n}(\boldsymbol{X}_t, \boldsymbol{y}_t)}{\partial \boldsymbol{y}'_{t+1}} \Delta \boldsymbol{y}_{t+1}. \tag{A47}$$

We invert equation (A47) as

$$\Delta \boldsymbol{y}_{t+1} = \left(\frac{\partial \boldsymbol{n}(\boldsymbol{X}_t, \boldsymbol{y}_t)}{\partial \boldsymbol{y}'_{t+1}} \right)^{+} (\boldsymbol{n}_{t+1} - \boldsymbol{n}(\boldsymbol{X}_t, \boldsymbol{y}_t)), \tag{A48}$$

where

$$\left(\frac{\partial \boldsymbol{n}(\boldsymbol{X}_t, \boldsymbol{y}_t)}{\partial \boldsymbol{y}'_{t+1}} \right)^{+} = \left(\frac{\partial \boldsymbol{n}(\boldsymbol{X}_t, \boldsymbol{y}_t)'}{\partial \boldsymbol{y}_{t+1}} \frac{\partial \boldsymbol{n}(\boldsymbol{X}_t, \boldsymbol{y}_t)}{\partial \boldsymbol{y}'_{t+1}} \right)^{-1} \frac{\partial \boldsymbol{n}(\boldsymbol{X}_t, \boldsymbol{y}_t)'}{\partial \boldsymbol{y}_{t+1}} \tag{A49}$$

is the Moore-Penrose inverse. Therefore, the conditional mean and variance of endowment income is

$$\mathbb{E}_t(\Delta \boldsymbol{y}_{t+1}) = \left(\frac{\partial \boldsymbol{n}(\boldsymbol{X}_t, \boldsymbol{y}_t)}{\partial \boldsymbol{y}'_{t+1}} \right)^{+} (\mathbb{E}_t[\boldsymbol{n}_{t+1}] - \boldsymbol{n}(\boldsymbol{X}_t, \boldsymbol{y}_t)), \tag{A50}$$

$$\mathrm{Var}_t(\Delta \boldsymbol{y}_{t+1}) = \left(\frac{\partial \boldsymbol{n}(\boldsymbol{X}_t, \boldsymbol{y}_t)}{\partial \boldsymbol{y}'_{t+1}} \right)^{+} \mathrm{Var}_t(\boldsymbol{n}_{t+1}) \left(\frac{\partial \boldsymbol{n}(\boldsymbol{X}_t, \boldsymbol{y}_t)}{\partial \boldsymbol{y}'_{t+1}} \right)^{+\prime}. \tag{A51}$$

Using the equilibrium equations at time t (A45), we write the conditional moments (A41) and (A42) as a function of $\boldsymbol{X}_t$:

$$\begin{aligned} \mathbb{E}_t[\boldsymbol{n}_{t+1}] =& \boldsymbol{\mu}(\boldsymbol{X}_t), && \text{(A52)} \\ \mathrm{Var}_t(\boldsymbol{n}_{t+1}) =& \boldsymbol{\Sigma}(\boldsymbol{X}_t). && \text{(A53)} \end{aligned}$$

Finally, we substitute these conditional moments into equations (A50) and (A51), which proves that the conditional moments of endowment income depend only on $\boldsymbol{X}_t$. QED

2. Model of Interest Rates

We model the conditional mean and variance of consumption growth in the linearized Euler equation (A29) as a function of characteristics:

$$p_t(n) = \boldsymbol{\Pi}'\boldsymbol{z}_t(n) + \pi_t(n). \tag{A54}$$

The vector $\boldsymbol{z}_t(n)$ contains the characteristics of country n that relate to the distribution of consumption growth. The scalar $\pi_t(n)$ is a latent state variable for country n, unobserved by the econometrician, that relates to the distribution of consumption growth. Equation (A54) corresponds to a row of the equilibrium equations (A45), where the bond price depends on the exogenous state variables.

3. Asset Demand

We model the conditional mean of real exchange rate growth as

$$\mathbb{E}_t[\Delta(e_{t+1} - v_{t+1})] = -\Theta(e_t - v_t) + \iota. \tag{A55}$$

Mean reversion in the real exchange rate implies a coefficient $\Theta \geq 0$. We assume that the conditional variance of real exchange rate growth is $\sigma^2_{i,t}(n) = \omega$. We model the conditional covariance between investor i's endowment income and real exchange rate growth as

$$-(\kappa - 1)\frac{\overline{\sigma}_{i,t}(n)}{\sigma^2_{i,t}(n)} = \boldsymbol{\Lambda}'\boldsymbol{x}_{i,t}(n) + \epsilon_{i,t}(n). \tag{A56}$$

The vector $\boldsymbol{x}_{i,t}(n)$ contains the characteristics of country n and the bilateral distance between countries i and n to capture the gravity effect. The scalar $\epsilon_{i,t}(n)$ is a latent state variable for country n, unobserved by the econometrician, that relates to the conditional covariance.

Substituting equations (A55) and (A56) in equation (A36), investor i's portfolio weight on the foreign bond n is

$$w_{i,t}(n) = \frac{\kappa}{2\gamma} + \lambda\mu_{i,t}(n) + \boldsymbol{\Lambda}'\boldsymbol{x}_{i,t}(n) + \epsilon_{i,t}(n), \tag{A57}$$

where $\lambda = \kappa/(\gamma\omega)$. The expected excess return of US investors on Japanese bonds (A30) is

$$\mu_{U,t}(J) = p_t(U) - p_t(J) - \Theta(e_t - v_t) + \iota. \tag{A58}$$

The expected excess return of Japanese investors on US bonds (A33) is

$$\mu_{J,t}(U) = p_t(J) - p_t(U) + \Theta(e_t - v_t) - \iota. \tag{A59}$$

Asset demand (A57) increases in the expected excess return $\mu_{i,t}(n)$ or equivalently decreases in the bond price through equation (A58) or (A59). The unobserved characteristic $\epsilon_{i,t}(n)$, which we call latent demand, captures the bilateral risk of investor i holding the foreign bond n. Latent demand ensures that the asset demand function matches the portfolio holdings data.

4. Model of Wealth

We assume that the portfolio flow, which is endowment income minus consumption in local currency, is exogenous in equations (A7) and (A11). Equation (13) generalizes equations (A7) and (A11) with multiple countries and asset classes, outside assets, and capital gains on the portfolio from the previous period.

5. Equilibrium

The exogenous state vector is $\boldsymbol{X}_t = [y_{i,t}, F_{i,t}, q_t(n), \boldsymbol{z}_t(n)', \boldsymbol{x}_{i,t}(n)', \pi_t(n), \epsilon_{i,t}(n)]'$ $\forall i, n \in \{U, J\}$. We have explicitly defined the equilibrium equations (A45) for wealth, portfolio choice, the exchange rate, and bond prices as a function of the exogenous state vector. Our system of seven equations consists of equation (A54) for the US and Japanese bond prices, equation (A57) for the asset demand of US and Japanese investors, equations (A7) and (A11) for the wealth of US and Japanese investors, and market clearing of Japanese bonds (A21). US bonds also clear by Walras's law.

We do not impose market clearing of consumption goods for the determination of the exchange rate, following Kouri (1983), Blanchard, Giavazzi, and Sa (2005), and Hau and Rey (2006). Our asset demand system is equivalent to the portfolio balance models (Kouri 1983; Blanchard, Giavazzi, and Sa 2005), except that the interest rates depend on the exogenous state variables instead of being constant. Hau and Rey (2006) extend the two-country model to equity markets and make three important modifications. First, the investors solve a pure portfolio choice model (without consumption choice) between a domestic riskless bond, domestic equity, and foreign equity. Second, the riskless bonds are in perfectly elastic supply, making their interest rates constant. Consequently, the market clearing equations for the two bonds hold trivially and do not play a direct role in the determination of the exchange rate. This feature is an important distinction from our asset demand system and the portfolio balance models. Third, they introduce a foreign exchange market, which equates net foreign equity investment to a residual supply function for foreign exchange. Their system of seven equations consists of the optimal portfolios for domestic and foreign investors and market clearing of foreign exchange, domestic equity, and foreign equity.

Appendix B. International Asset Pricing Model

We extend the two-country general equilibrium model in Appendix A to multiple countries and asset classes. We use the general equilibrium model as a microfoundation to help design the asset demand system in Section II. We replace the consumption Euler equations with a model of short-term rates. Since the optimal portfolios in a traditional model do not explain features such as the gravity effect and home bias, we replace them with asset demand functions. Finally, we introduce a model of wealth with exogenous portfolio flows. The model of short-term rates, the asset demand functions, the model of wealth, and market clearing of all assets determine the equilibrium exchange rate and asset prices.

Relative to the empirical application in Section II, we make two assumptions to keep the portfolio choice problem static and to simplify the exposition. We assume real rather than nominal debt, and we do not distinguish short- versus long-term debt in a two-period model.

A. Endowments, Consumption, and Price Indices

We index the countries as $n = 0, \ldots, N$, where $n = 0$ is the rest of the world. At time t, investor i receives an endowment $Y_{i,t}$ of a differentiated consumption good. The investor has preferences for consumption variety and trade subject to trade costs. The investor consumes $C_{i,t}(n)$ units of country n's good at price $B_{i,t}(n)$. All good prices are in local currency, and we normalize the domestic good price to one (i.e., $B_{i,t}(i) = 1$).

The investor's consumption index is a CES aggregator over all goods:

$$C_{i,t} = \left(\sum_{n=0}^{N} C_{i,t}(n)^{1-1/\phi} \right)^{\frac{1}{1-1/\phi}}, \tag{B1}$$

where $\phi > 0$ is the elasticity of substitution. Utility maximization implies that the total consumption expenditure is

$$B_{i,t}C_{i,t} = \sum_{n=0}^{N} B_{i,t}(n)C_{i,t}(n), \tag{B2}$$

where the consumer price index is

$$B_{i,t} = \left(\sum_{n=0}^{N} B_{i,t}(n)^{1-\phi} \right)^{\frac{1}{1-\phi}}. \tag{B3}$$

We assume the presence of iceberg trade costs such that $\tau_{i,t}(n) \geq 1$ units of country n's good become one unit of country i's consumption. The law of one price implies that $B_{i,t}(n) = \tau_{i,t}(n)E_t(n)/E_t(i)$. Substituting these good prices in equation (B3), the consumer price index is

$$B_{i,t} = \left(\sum_{n=0}^{N} \left(\frac{\tau_{i,t}(n)E_t(n)}{E_t(i)} \right)^{1-\phi} \right)^{\frac{1}{1-\phi}}. \tag{B4}$$

That is, the exchange rates and trade costs fully determine the consumer price indices.

Let $\boldsymbol{X}_t$ be an exogenous state vector at time t, which contains all relevant information for the distribution of endowment income at time $t+1$. The endowment income is conditionally lognormal (A6).

B. Asset Markets

Each country has debt that is indexed to its consumer price index, which has price $P_t(n, S)$ in local currency at time t and a payoff $B_{n,t+1}/B_{n,t}$ in local currency at time $t+1$. We denote its gross nominal return in local currency as $R_{t+1}(n, S) = B_{n,t+1}/(P_t(n, S)B_{n,t})$. Each country also has equity that is a nominal claim on the endowment income at time $t + 1$. Equity has price $P_t(n, E)$ in local currency at time t and a payoff $Y_{n,t+1}$ at time $t + 1$. We denote its gross nominal return in local currency as $R_{t+1}(n, E) = Y_{n,t+1}/P_t(n, E)$. We normalize the supply of equity in each country to $Q_t(n, E) = 1$ in local currency.

Let $\boldsymbol{r}_{i,t+1} + \Delta\boldsymbol{e}_{t+1}$ be a $(2N + 1)$-dimensional vector of log nominal returns in US dollars from time t to $t + 1$, including the outside asset (indexed as $n = 0$) for each asset class but excluding investor i's domestic debt. 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 local currency is

$$\overline{\boldsymbol{r}}_{i,t+1} = \boldsymbol{r}_{i,t+1} + \Delta \boldsymbol{e}_{t+1} - (\Delta e_{t+1}(i) + \Delta b_{i,t+1})\mathbf{1}, \tag{B5}$$

where $\mathbf{1}$ is a vector of ones. We denote log real returns on investor i's domestic debt as $\overline{r}_{t+1}(i,S) = r_{t+1}(i,S) - \Delta b_{i,t+1}$.

C. Investors and Governments

1. Investors

At time t, investor i receives an endowment $Y_{i,t}$ and consumes $B_{i,t}C_{i,t}$ in local currency. The investor's wealth after consumption in dollars is

$$A_{i,t} = E_t(i)\underbrace{(Y_{i,t} - B_{i,t}C_{i,t})}_{F_{i,t}}. \tag{B6}$$

We refer to $F_{i,t}$ as the portfolio flow in the asset demand system that we develop. Let $\boldsymbol{w}_{i,t}$ be a $(2N+1)$-dimensional vector of portfolio weights. Its elements are the share $w_{i,t}(n,l)$ of its wealth that the investor allocates to asset class l in country n. The investor allocates the remaining share $1 - \boldsymbol{w}_{i,t}'\mathbf{1}$ to its domestic debt. The gross real portfolio return is

$$R_{i,t+1} = \exp(\overline{r}_{t+1}(i,S)) + \boldsymbol{w}_{i,t}'(\exp(\overline{\boldsymbol{r}}_{i,t+1}) - \exp(\overline{r}_{t+1}(i,S)\mathbf{1})) \tag{B7}$$

in local currency from time t to $t+1$. The investor pays a lumpsum tax of $T_{i,t+1}$ units of consumption and consumes its remaining wealth at time $t+1$. Thus, its intertemporal budget constraint is

$$C_{i,t+1} = R_{i,t+1}\frac{A_{i,t}}{E_t(i)B_{i,t}} - T_{i,t+1}. \tag{B8}$$

In contrast to equations (A9) and (A13), the endowment income at time $t+1$ enters through the portfolio return because equity (i.e., a claim on the endowment income) is tradeable.

Investors have constant relative risk aversion preferences. The preference parameter $\gamma > 0$ is relative risk aversion, and $\beta > 0$ is the subjective discount factor. Investor i solves a consumption and portfolio choice problem at time t:

$$\max_{C_{i,t},\boldsymbol{w}_{i,t}} \frac{C_{i,t}^{1-\gamma}}{1-\gamma} + \beta\frac{\mathbb{E}_t\left[C_{i,t+1}^{1-\gamma}\right]}{1-\gamma}, \tag{B9}$$

subject to the intertemporal budget constraint (B8).

2. Governments

We model governments separately from investors to define an exogenous supply of debt. The government in country n inelastically issues real debt, indexed to its consumer price index, with face value $Q_t(n,S)$ at time t. Thus, the quantity of debt $Q_t(n,S)$ is exogenous, but its price $P_t(n,S)$ is endogenous.

At time t, the government in country n consumes $G_{n,t}(m)$ units of country n's good at price $B_{n,t}(m)$. The debt finances government expenditure of

$$P_t(n,S)Q_t(n,S) = \sum_{m=0}^{N} B_{n,t}(m)G_{n,t}(m) = B_{n,t}G_{n,t}, \tag{B10}$$

where

$$G_{n,t} = \left(\sum_{m=0}^{N} G_{n,t}(m)^{1-1/\phi}\right)^{\frac{1}{1-1/\phi}}. \tag{B11}$$

To satisfy its intertemporal budget constraint (i.e., $B_{n,t+1}T_{n,t+1} = R_{t+1}(n,S)B_{n,t}G_{n,t}$), the government collects a lumpsum tax of $T_{n,t+1} = Q_t(n,S)/B_{n,t}$ units of consumption from its domestic investors at time $t+1$.

D. Market Clearing

Market clearing of country n's good at time t is

$$Y_{n,t} = \sum_{i=0}^{N} \tau_{i,t}(n)(C_{i,t}(n) + G_{i,t}(n)). \tag{B12}$$

Using standard properties of the CES aggregator, we rewrite this equation as

$$E_t(n)Y_{n,t} = \sum_{i=0}^{N} (\tau_{i,t}(n)E_t(n))^{1-\phi}(E_t(i)B_{i,t})^{\phi}(C_{i,t} + G_{i,t}). \tag{B13}$$

Endowment income in US dollars equals total consumption and government expenditures for each good. We also have equation (14) for market clearing of debt and equity for each country at time t.

Market clearing of country n's good at time $t+1$ is

$$E_{t+1}(n)Y_{n,t+1} = \sum_{i=0}^{N}(\tau_{i,t+1}(n)E_{t+1}(n))^{1-\phi}(E_{t+1}(i)B_{i,t+1})^{\phi}C_{i,t+1}, \tag{B14}$$

following the same derivation as equation (B13). Endowment income in US dollars equals total consumption expenditures for each good.

E. Optimal Consumption and Portfolio Choice

The first-order conditions for consumption and portfolio choice are

$$\mathbb{E}_t\left[\beta\left(\frac{C_{i,t+1}}{C_{i,t}}\right)^{-\gamma}\exp(\overline{\boldsymbol{r}}_{i,t+1})\right] = \mathbf{1}. \tag{B15}$$

Equation (B15) for the row corresponding to investor i's own debt (i.e., $n=i$ and $l=S$) is

$$\begin{aligned} 1 =& \mathbb{E}_t[\exp(\log(\beta) - \gamma\Delta c_{n,t+1} + r_{t+1}(n,S) - \Delta b_{n,t+1})] \qquad \text{(B16)} \\ \approx& \exp\left(\log(\beta) - \gamma\mathbb{E}_t[\Delta c_{n,t+1}] + \mathbb{E}_t[r_{t+1}(n,S) - \Delta b_{n,t+1}] + \frac{\gamma^2\mathrm{Var}_t(\Delta c_{n,t+1})}{2}\right). \end{aligned}$$

Taking logarithms of both sides and rearranging, we have a linearized Euler equation:

$$\mathbb{E}_t[r_{t+1}(n,S)] = -\log(\beta) + \mathbb{E}_t[\Delta b_{n,t+1}] + \gamma\mathbb{E}_t[\Delta c_{n,t+1}] - \frac{\gamma^2\mathrm{Var}_t(\Delta c_{n,t+1})}{2}. \tag{B17}$$

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

$$\boldsymbol{\mu}_{i,t} = \mathbb{E}_t[\overline{\boldsymbol{r}}_{i,t+1} - \overline{r}_{t+1}(i,S)\mathbf{1}], \tag{B18}$$

where its elements are $\mu_{i,t}(n,l)$ for asset class l in country n. We denote the covariance matrix of log real returns in investor i's local currency as

$$\boldsymbol{\Sigma}_{i,t} = \mathbb{E}_t[(\overline{\boldsymbol{r}}_{i,t+1} - \mathbb{E}_t[\overline{\boldsymbol{r}}_{i,t+1}])\overline{\boldsymbol{r}}'_{i,t+1}]. \tag{B19}$$

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. By Campbell and Viceira (2002, equation 2.26), investor i's optimal portfolio is

$$\boldsymbol{w}_{i,t} = \frac{1}{\gamma}\boldsymbol{\Sigma}_{i,t}^{-1}\left(\boldsymbol{\mu}_{i,t} + \frac{\boldsymbol{\sigma}_{i,t}^2}{2}\right). \tag{B20}$$

F. Equilibrium

At time t, the exogenous state vector $\boldsymbol{X}_t$ includes endowment income $\boldsymbol{y}_t$ and bond supply $\boldsymbol{q}_t$. By the budget constraint (B6), we can write the consumption policies in terms of wealth rather than consumption, which is more convenient notation for the asset demand system that we develop. Thus, the policy variables are wealth $\boldsymbol{A}_t = [A_{0,t}, \ldots, A_{N,t}]'$ and portfolio choice $\boldsymbol{w}_t = [\boldsymbol{w}'_{0,t}, \ldots, \boldsymbol{w}'_{N,t}]'$. The endogenous prices are the exchange rates $\boldsymbol{e}_t$ and asset prices $\boldsymbol{p}_t$.

1. Equilibrium at Time $t+1$

We write the intertemporal budget constraint (B8) for all countries as a vector:

$$\boldsymbol{c}_{t+1} = \boldsymbol{c}(\boldsymbol{e}_{t+1}; \boldsymbol{A}_t, \boldsymbol{w}_t, \boldsymbol{e}_t, \boldsymbol{p}_t; \boldsymbol{q}_t, \boldsymbol{y}_t, \boldsymbol{y}_{t+1}). \tag{B21}$$

We write market clearing of consumption goods at time $t+1$ (B14) as an implicit function:

$$\boldsymbol{e}_{t+1} = \boldsymbol{e}(\boldsymbol{c}_{t+1}; \boldsymbol{y}_{t+1}). \tag{B22}$$

The solution to this system of equations is

$$[\boldsymbol{c}'_{t+1}, \boldsymbol{e}'_{t+1}]' = \boldsymbol{m}_{t+1}(\boldsymbol{A}_t, \boldsymbol{w}_t, \boldsymbol{e}_t, \boldsymbol{p}_t; \boldsymbol{q}_t, \boldsymbol{y}_t, \boldsymbol{y}_{t+1}). \tag{B23}$$

2. Equilibrium at Time t

Optimal consumption (B17) and portfolio choice (B20) depend on the conditional mean and variance of a vector of endogenous variables:

$$\boldsymbol{n}_{t+1} = [\Delta\boldsymbol{c}'_{t+1}, \Delta\boldsymbol{b}'_{t+1}, \Delta\boldsymbol{e}'_{t+1}, \boldsymbol{y}'_{t+1}]'. \tag{B24}$$

Given the distribution of endowment income (A6) and the solution at time $t+1$ (B23), we compute the conditional moments of the endogenous variables (B24) as

$$\mathbb{E}_t[\boldsymbol{n}_{t+1}] = \boldsymbol{\mu}(\boldsymbol{A}_t, \boldsymbol{w}_t, \boldsymbol{e}_t, \boldsymbol{p}_t; \boldsymbol{X}_t), \tag{B25}$$

$$\mathrm{Var}_t(\boldsymbol{n}_{t+1}) = \boldsymbol{\Sigma}(\boldsymbol{A}_t, \boldsymbol{w}_t, \boldsymbol{e}_t, \boldsymbol{p}_t; \boldsymbol{X}_t). \tag{B26}$$

Substituting the conditional moments (B25) and (B26), we write optimal consumption (B17) and portfolio choice (B20) at time t as an implicit function:

$$[\boldsymbol{A}_t', \boldsymbol{w}_t']' = \boldsymbol{m}_{c,w}(\boldsymbol{e}_t, \boldsymbol{p}_t; \boldsymbol{X}_t). \tag{B27}$$

Importantly, the optimal portfolios depend on the level of exchange rates and asset prices. We write market clearing of consumption goods (B13) and assets (14) at time t as an implicit function:

$$[\boldsymbol{e}_t', \boldsymbol{p}_t']' = \boldsymbol{m}_{e,p}(\boldsymbol{A}_t, \boldsymbol{w}_t; \boldsymbol{q}_t, \boldsymbol{y}_t). \tag{B28}$$

The solution to this system of equations is

$$[\boldsymbol{A}_t', \boldsymbol{w}_t', \boldsymbol{e}_t', \boldsymbol{p}_t']' = \boldsymbol{m}_t(\boldsymbol{X}_t). \tag{B29}$$

G. Asset Demand System

We develop an asset demand system by making additional assumptions about the conditional moments (B25) and (B26), applying Proposition 1. The purpose of these assumptions is to replace the consumption Euler equations with a model of short-term rates and the optimal portfolios with asset demand functions.

1. Model of Short-Term Rates

We model the conditional mean and variance of consumption growth and the conditional mean of inflation in the linearized Euler equation (B17) as a function of characteristics (4). The vector $\boldsymbol{z}_t(n)$ contains the characteristics of country n that relate to the distribution of consumption growth and inflation. The scalar $\pi_t(n)$ is a latent state variable for country n, unobserved by the econometrician, that relates to the distribution of consumption growth and inflation. Equation (4) corresponds to a row of the equilibrium equations (B29), where the bond price depends on the exogenous state variables.

2. Asset Demand

We model the expected excess returns as equation (3). We assume that log real returns have a one-factor structure, such that the covariance matrix is

$$\boldsymbol{\Sigma}_{i,t} = \boldsymbol{\Omega}_{i,t}\boldsymbol{\Omega}_{i,t}' + \operatorname{diag}(\boldsymbol{\omega}). \tag{B30}$$

$\mathbf{\Omega}_{i,t}$ is a vector of factor loadings (normalizing the variance of the factor to one), where its elements are $\Omega_{i,t}(n,l)$ for asset class l in country n. $\operatorname{diag}(\boldsymbol{\omega})$ is a diagonal matrix of idiosyncratic variances. The idiosyncratic variance $\omega(l)$ is constant across investors and within each asset class l. We motivate equation (B30) 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, Moskowitz, and Pedersen 2013; Dahlquist and Hasseltoft 2013; Jotikasthira, Le, and Lundblad 2015).

By the Woodbury matrix identity, the inverse of the covariance matrix (B30) is

$$\mathbf{\Sigma}_{i,t}^{-1} = \operatorname{diag}(\boldsymbol{\omega})^{-1}\left(\mathbf{I} - \frac{\mathbf{\Omega}_{i,t}\mathbf{\Omega}_{i,t}'\operatorname{diag}(\boldsymbol{\omega})^{-1}}{1+\mathbf{\Omega}_{i,t}'\operatorname{diag}(\boldsymbol{\omega})^{-1}\mathbf{\Omega}_{i,t}}\right), \tag{B31}$$

where $\lambda_l = 1/(\gamma\omega(l))$ and

$$\kappa_{i,t} = \frac{\mathbf{\Omega}_{i,t}'\operatorname{diag}(\boldsymbol{\omega})^{-1}\left(\boldsymbol{\mu}_{i,t}+\boldsymbol{\sigma}_{i,t}^2/2\right)}{1+\mathbf{\Omega}_{i,t}'\operatorname{diag}(\boldsymbol{\omega})^{-1}\mathbf{\Omega}_{i,t}}. \tag{B32}$$

Therefore, investor i's optimal portfolio (B20) is

$$w_{i,t}(n,l) = \lambda_l\left(\mu_{i,t}(n,l) + \frac{\sigma_{i,t}^2(n,l)}{2} - \kappa_{i,t}\Omega_{i,t}(n,l)\right). \tag{B33}$$

Equation (B33) implies that the portfolio weight increases in the expected return $\mu_{i,t}(n,l)$ and decreases in the factor loading $\kappa_{i,t}\Omega_{i,t}(n,l)$.

We model investor i's risk exposure for asset class l in country n as

$$\lambda_l\left(\frac{\sigma_{i,t}^2(n,l)}{2} - \kappa_{i,t}\Omega_{i,t}(n,l)\right) = \mathbf{\Lambda}_l'\boldsymbol{x}_{i,t}(n) + \epsilon_{i,t}(n,l). \tag{B34}$$

The vector $\boldsymbol{x}_{i,t}(n)$ contains the characteristics of country n and the bilateral distance between countries i and n to capture the gravity effect. The scalar $\epsilon_{i,t}(n,l)$ is a latent state variable for country n, unobserved by the econometrician, that relates to the risk exposure.

Substituting equation (B34) in equation (B33), investor i's portfolio weight on asset class l in country n is

$$w_{i,t}(n,l) = \lambda_l\mu_{i,t}(n,l) + \mathbf{\Lambda}_l'\boldsymbol{x}_{i,t}(n) + \epsilon_{i,t}(n,l). \tag{B35}$$

We refer to Koijen and Yogo (2019, Corollary 1) for a derivation of the logit model of asset demand (11) under short-sale constraints and additional restrictions on the factor model of returns.

3. Model of Wealth

We assume that the portfolio flow, which is endowment income minus consumption in local currency, is exogenous in equation (B6). Equation (13) generalizes equation (B6) with capital gains on the portfolio from the previous period.

4. Equilibrium

The exogenous state vector is $\boldsymbol{X}_t = [y_{i,t}, F_{i,t}, q_t(n), \boldsymbol{z}_t(n)', \boldsymbol{x}_{i,t}(n)', \pi_t(n), \epsilon_{i,t}(n,l)]'$ $\forall i, n \in \{0, \ldots, N\}$ and $l \in \{S, E\}$. We have explicitly defined the equilibrium equations (B29) for wealth, portfolio choice, exchange rates, and asset prices as a function of the exogenous state vector. Our system of equations consists of equation (4) for the debt prices, equation (11) for asset demand, equation (B6) for the model of wealth, and market clearing of all assets (14). We do not impose market clearing of consumption goods for the determination of exchange rates and asset prices.

Appendix C. Data Construction

We construct international portfolio holdings in three steps. First, we construct the total amounts outstanding by year, issuer country, and asset class. Second, we construct the foreign portfolio holdings by year, investor country, issuer country, and asset class. Third, we merge the data from the first two steps and construct the domestic portfolio holding as the total amount outstanding minus the sum of foreign portfolio holdings.

A. Total Amounts Outstanding

Table C1 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 our sample, 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.

Table C1
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) BIS (to 2009)	OECD
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) BIS (to 2008)	OECD
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

Note.—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).

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 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 splits 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

[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

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 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.

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.

C. Asset Prices

The exchange rates are from the International Monetary Fund (2003–2020b). For the relative price indices, we use the purchasing power parity conversion factors for GDP in current international dollars from the World Bank (2003–2020). We construct the relative price index for the euro area as a GDP-weighted average over the ten countries in our sample.

The short-term rates are the three-month interbank rates from Datastream (Refinitiv 2003–2020). 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. Equity prices are market-to-book equity from the MSCI (2003–2020). Equity returns on the MSCI Country Indexes are from Datastream.

D. Asset Characteristics

The World Bank (2003–2020) is our data source for the macro variables and population. 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 and Poors (2003–2020). We convert the rating to a continuous measure by fitting a smooth curve to the ten-year default rate (Standard and 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 for CCC, 0.2526 for 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 D. Counterfactual Wealth

Let $\boldsymbol{E}_C$ be a 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 (13), we define investor i's counterfactual wealth as

$$A_{i,C} = O_{i,C} + \sum_{l \in \{S,L,E\}} \sum_{n=1}^{N} (A_{i,t} w_{i,t}(n,l) + F_{i,C}(n,l)) \frac{E_C(n) P_C(n,l)}{E_t(n) P_t(n,l)}. \quad \text{(D1)}$$

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

$$w_{i,C}(n,l; \boldsymbol{E}_C, \boldsymbol{P}_C, \zeta_{i,C}) = \frac{\delta_{i,C}(n,l; \boldsymbol{E}_C, \boldsymbol{P}_C) \exp(-\zeta_{i,C})}{1 + \sum_{m=1}^{N} \delta_{i,C}(m,l; \boldsymbol{E}_C, \boldsymbol{P}_C) \exp(-\zeta_{i,C})} w_{i,C}(l; \boldsymbol{E}_C, \boldsymbol{P}_C). \quad \text{(D2)}$$

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

$$A_{i,C} = \frac{O_{i,C}}{1 - \sum_{l \in \{S,L,E\}} \sum_{n=1}^{N} w_{i,C}(n,l; \boldsymbol{E}_C, \boldsymbol{P}_C, \zeta_{i,C})}. \quad \text{(D3)}$$

Given counterfactual wealth $A_{i,C}$, we can keep counterfactual outside wealth $O_{i,C}$ constant by changing $\zeta_{i,C}$. Thus, the demand shifters determine the levels of wealth, which is equivalent to determining the levels of consumption in the general equilibrium model in Appendix B.

The counterfactual exchange rates and asset prices satisfy $N-11$ equations for the model of short-term rates (4) and the market clearing equations:

$$E_C(n) P_C(n,l) Q_C(n,l) = \sum_{i=1}^{I} A_{i,C} w_{i,C}(n,l; \boldsymbol{E}_C, \boldsymbol{P}_C, \zeta_{i,C}). \quad \text{(D4)}$$

We solve jointly for the counterfactual exchange rates and asset prices and the counterfactual demand shifters that keep the outside wealth constant for all investors.

In the first step of the variance decomposition, we change the asset quantities from $Q_C(n,l) = Q_t(n,l)$ to $Q_C(n,l) = Q_{t+1}(n,l)$ and the portfolio flows from $F_{i,C}(n,l) = 0$ to $F_{i,C}(n,l) = F_{i,t}(n,l)$. 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 observations in year $t + 1$. The counterfactual demand shifters are equal to zero.

Appendix E. Sensitivity Analysis

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. Using data on the S&P 500 from 1946 to 2020 (Finaeon 2023), we 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 E1, the estimated demand coefficients hardly change, which implies that the asset demand estimation is not sensitive to sampling error in the predictive regression.

Table E1
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

Note.—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, Table 5.2). The annual sample period is 2003 to 2020.