Exchange Rates and Asset Prices in a Global Demand System*

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Abstract

Using international holdings data, we estimate a demand system for financial assets across 36 countries. The demand system provides a unified framework for decomposing variation in exchange rates, long-term yields, and stock prices; interpreting major economic events such as the European sovereign debt crisis; and estimating the convenience yield on US assets. Macro variables and policy variables (i.e., short-term rates, debt quantities, and foreign exchange reserves) account for 55 percent of the variation in exchange rates, 57 percent of long-term yields, and 69 percent of stock prices. The average convenience yield is 2.15 percent on US long-term debt and 1.70 on US equity.

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Global investors hold financial assets across many countries and have exchange rate exposure not only through short-term debt but also long-term debt and equity. The portfolio decisions of these investors across countries and asset classes are important for exchange rates, long-term yields, and stock prices. Government policies are also important. Conventional monetary policy determines the short-term rate. Fiscal policy and unconventional monetary policy affect the supply of domestic debt. Central banks hold foreign debt in foreign exchange reserves, affecting the residual supply of foreign debt. All of these forces determine exchange rates and asset prices through market clearing of global financial markets.

We develop an asset pricing model to study sources of variation in exchange rates, long-term yields, and stock prices across 36 countries from 2002 to 2017. We model investors at the country level to match international holdings of short-term debt, long-term debt, and equity in the International Monetary Fund's (IMF) Coordinated Portfolio Investment Survey. We start with market clearing identities for these three asset classes across all countries. The supply of each asset must equal the demand across all investor countries and foreign exchange reserves. Every asset pricing model is ultimately a model of asset demand that arises from portfolio choice, combined with market clearing. This paper is the first attempt to take the portfolio choice implications to their logical conclusion and to actually match international holdings together with asset prices across all countries.

Starting with a portfolio choice model, Koijen and Yogo (2019) show that an investor's optimal portfolio weights could be expressed as a logit function of asset characteristics and latent demand (i.e., characteristics unobserved by the econometrician). Following their approach, we specify the asset demand of investor countries and foreign exchange reserves to depend on the market-to-book ratio (equivalently, yield in the case of debt), the real exchange rate, and macro variables such as gross domestic product (GDP), real GDP per capita, and inflation. Demand also depends on risk measures including equity volatility and sovereign debt ratings. Bilateral variables including exports, imports, and the distance between investor and issuer countries are important for explaining cross-country financial investment (Portes, Rey, and Oh 2001; Portes and Rey 2005). We estimate the demand system by instrumental variables because exchange rates, asset prices, and latent demand are jointly endogenous. The demand for an asset depends directly on its own characteristics and indirectly on the characteristics of other assets through market clearing. Therefore, market clearing defines a particular nonlinear function of all asset characteristics as an instrument. The estimated demand elasticities are 42 for short-term debt, 4.2 for long-term debt, and 1.9 for equity. That is, equity demand decreases by 1.9 percent per one percent price increase.

Based on the estimated demand system and market clearing, we decompose the variance of annual changes in exchange rates and asset prices. Macro variables account for 26 percent, short-term rates account for 8 percent, long-term debt quantities account for 2 percent, and foreign exchange reserves account for 19 percent of the variation in exchange rates. These fundamental sources jointly account for 55 percent of the variation in exchange rates. The importance of latent demand that accounts for the remaining 45 percent is geographically concentrated in large investor countries. In particular, latent demand of US and European countries substituting across asset classes accounts for 16 percent of the variation in exchange rates.

While the macro variables account for 16 percent of the variation in long-term yields, the policy variables are much more important. Short-term rates account for 9 percent, long-term debt quantities account for 20 percent, and foreign exchange reserves account for 11 percent of the variation in long-term yields. These policy variables jointly account for 40 percent of the variation in long-term yields. In contrast, macro variables are the primary determinants of stock prices, accounting for 57 percent of the variation.

The demand system approach is also useful for interpreting major economic events, which we illustrate through a case study of the European sovereign debt crisis. We decompose sovereign yield spreads between Germany and the US as well as the southern euro countries and Germany. On the one hand, the relative timing of monetary easing accounts for almost all of the variation in the long-term yield spread between Germany and the US. Short-term rates account for 53 percent, and long-term debt quantities account for 15 percent of the variation in the long-term yield spread. On the other hand, the relative macro and fiscal experiences account for most of the variation in the long-term yield spreads between the southern euro countries and Germany. Macro variables account for 64 percent, and long-term debt quantities account for 14 percent of the variation in the long-term yield spreads.

US assets enjoy a special status in global financial markets because the US dollar is the most important reserve currency (Gourinchas and Rey 2007). The demand system captures the special status of US assets through fixed effects for US issuance interacted with year. Based on the estimated demand system and market clearing, we estimate the convenience yield on the US dollar, long-term debt, and equity. We also trace the investor origins of the convenience yield into a sum of special-status demand by investor countries and foreign exchange reserves. In the absence of special status, the expected annual appreciation of the US dollar relative to a value-weighted portfolio of foreign currencies would be 1.28 percentage points higher. The US long-term yield would be 2.15 percentage points higher, of which we attribute 0.48 percent to foreign exchange reserves, 0.51 percent to European investors, and 0.52 percent to Pacific investors. The US annual expected stock return would be 1.70 percentage points higher.

A. *Related Literature*

We relate this paper to the previous literature in the context of a two-country model of financial markets. Each country has a short-term debt market and an equity market, so there are four market clearing equations in total. There are five asset prices that enter the market clearing equations: short-term rates in each country, stock prices in each country, and the exchange rate. In traditional models of international finance, the consumption goods market determines the exchange rate, so that financial markets do not directly determine the exchange rate. Motivated by the empirical failure of traditional models, an alternative approach known as "portfolio balance models" relies entirely on financial markets for exchange rate determination.

In a model with only short-term debt, Kouri (1976) uses market clearing in the foreign short-term debt market for exchange rate determination, assuming that the foreign short-term rate is fixed.[1] Kouri and De Macedo (1978) resolve the problem of five asset prices in four market clearing equations by introducing a fifth equation for relative cash demand with the exchange rate as the relative price. Hau and Rey (2006) and Camanho, Hau, and Rey (2018) use market clearing in equity markets to jointly determine stock prices and the exchange rate. They introduce a third equation for the spot exchange rate, which depends on the imbalance between domestic demand for foreign equity and vice versa. Gabaix and Maggiori (2015) assume segmentation in short-term debt markets. Only speculators can hold both countries' debt, whose limited arbitrage capacity determines the exchange rate.

We take this literature that focuses on bilateral models in a more empirical direction that easily accommodates market clearing across multiple asset classes and many countries. We add long-term debt markets to study long-term yields in conjunction with short-term rates and stock prices. As in Hau and Rey (2006), we allow for substitution across asset classes so that the demand for long-term debt and equity could feed back into exchange rates. We use market clearing across all three asset classes for exchange rate determination, conditional on central bank policy that determines short-term rates.

Previous papers estimate demand elasticities of institutions and households for long-term debt and equity. They find less elastic demand than what asset pricing models would imply if assets were close substitutes within the same asset class. Krishnamurthy and Vissing-Jørgensen (2007) estimate demand elasticities for US Treasury debt. Koijen et al. (2018) estimate demand elasticities for sovereign debt in the euro area. Koijen and Yogo (2019) estimate demand elasticities for the cross section of US equity, and Koijen, Richmond, and

[1]Alternatively, Blanchard, Giavazzi, and Sa (2005) and Gourinchas (2008) use market clearing in the domestic equity market for exchange rate determination, assuming that the domestic stock price is fixed. This assumption is unappealing in our context because stock prices are direct objects of interest.

Yogo (2019) estimate demand elasticities for the cross-section of US and UK equity. These papers use institutional and household holdings within a country, while we use aggregate holdings at the country level. An advantage of our approach is that we estimate demand elasticities for all countries and asset classes, based on a demand system that allows for all substitution effects. The previous papers implicitly rule out substitution effects outside the countries and asset classes that their data cover.

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 covers the three asset classes across all developed and many emerging markets. An important difference is that our model matches international holdings together with asset prices. The literature on factor models uses data on asset prices and factors only, ignoring the portfolio choice implications of international holdings data. The demand system approach sheds light on the sources of common factors in global stock, bond, and currency markets.

The remainder of the paper is organized as follows. In Section I, we describe the data on international holdings and asset prices. We also present some reduced-form facts that support the formal analysis. In Section II, we present an asset demand system that matches observed international holdings and implies flexible substitution within and across asset classes. We also discuss how the asset demand system and market clearing determine exchange rates and asset prices. In Section III, we discuss the identifying assumption, describe the estimation procedure, and present the estimated demand system. In Section IV, we decompose exchange rates and asset prices based on the estimated demand system and market clearing. We also present a case study of the European sovereign debt crisis. In Section V, we estimate the convenience yield on US assets. Section VI concludes.

I. Data on International Holdings and Asset Prices

We briefly describe the data on international holdings and asset prices. We refer the reader to Appendix A for further details. We then present some reduced-form facts that support the formal analysis in the subsequent sections.

A. Data Construction

The Coordinated Portfolio Investment Survey contains each investor country's year-end holdings of foreign financial assets in US dollars by asset class and issuer country. The three asset classes are short-term debt (i.e., one year or less in maturity), long-term debt (i.e., greater than one year in maturity), and equity. The data also contain foreign exchange reserves, which are central bank holdings of foreign financial assets. The IMF aggregates foreign exchange reserves across all central banks for confidentiality. Therefore, we treat the aggregate portfolio of foreign exchange reserves as an investor unit.

We measure the supply of each asset by aggregating holdings across all investor countries and foreign exchange reserves. For short- and long-term debt, our measure corresponds to the total amount held by foreign investors. At the country level, domestically held debt is both an asset and a liability, so it does not count towards supply or wealth according to the national accounting identities. In contrast, domestically held equity is an asset that is part of wealth. Therefore, we measure the supply of equity as total stock market capitalization by country, published by the World Bank. We construct the amount of domestically held equity by subtracting the aggregate foreign holdings from total stock market capitalization.

Short-term rates are 3-month interbank rates from Thomson Reuters Datastream. We use the 10-year benchmark government bond yields from Datastream and (in a few cases of missing data) OECD's Monetary and Financial Statistics. We fit a Nelson and Siegel (1987) zero-coupon yield curve for each country, assuming that the 10-year benchmark yield is the par yield. Throughout the paper, the long-term yield refers to the 10-year zero-coupon yield, which we assume is the representative yield of long-term debt in the international holdings data.[2] Stock returns and market-to-book equity for countries in the MSCI ACWI Index are from Datastream and MSCI, respectively. Exchange rates are from the IMF's International Financial Statistics. Throughout the paper, exchange rates are in US dollars per local currency unit. We use year-end values of all exchange rates and asset prices to align with the year-end values of international holdings.

The merged sample of international holdings and asset prices covers 2002 to 2017. The financial assets are held by 88 investor countries plus foreign exchange reserves. We refer to Table A1 in Appendix A for a complete list of investor countries, which we group by MSCI classification for presentation purposes. There are 36 issuer countries with complete data on asset prices and characteristics. This covers all 22 countries in the MSCI World Index and 14 of 21 countries in the MSCI Emerging Markets Index. Ten of the 36 countries are in

[2]The important point of this simplifying assumption is that the 3-month rate and the 10-year yield capture the level and the slope of the term structure of interest rates. We use the 10-year maturity to estimate the slope because the data on the benchmark government bond yields are most complete at that maturity.

the euro area, and the Hong Kong dollar is pegged to the US dollar. Therefore, the sample contains 25 independent exchange rates relative to the US dollar. We aggregate all issuer countries outside the 36 countries as an "outside asset" for each asset class.

B. Summary of Global Financial Markets

Table 1 summarizes financial markets across 36 countries in 2017. The US short-term debt market was \$822.7 billion, of which central banks held 34 percent in foreign exchange reserves. The US long-term debt market was \$7,402 billion, of which central banks held 28 percent in foreign exchange reserves. The US equity market was \$32,121 billion, of which central banks held 1 percent in foreign exchange reserves. Thus, foreign exchange reserves account for a significant share of US debt but not equity.

Foreign exchange reserves also account for a significant share of debt in the euro area and Japan, which are important reserve currencies. Central banks held 26 percent of short-term debt in the euro area, 31 percent of German long-term debt, and 22 percent of Japanese long-term debt in foreign exchange reserves. Among the emerging markets, foreign exchange reserves are important in China. Central banks held 17 and 25 percent of Chinese short- and long-term debt, respectively, in foreign exchange reserves. The large size of foreign exchange reserves suggests that 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 2017. Foreign exchange reserves are the largest investor unit in both short- and long-term debt markets. Central banks held \$912 billion of short-term debt and \$4,381 billion of long-term debt in foreign exchange reserves across all countries. Unsurprisingly, large developed countries such as Germany, Japan, the UK, and the US appear in the top ten list. Ireland, Luxembourg, and the Cayman Islands also appear in the top ten list for both short- and long-term debt. These countries are offshore financial centers through which other countries invest because of favorable regulation and taxes. We refer to Appendix A for a further discussion of offshore financial centers and how we construct the international holdings data to avoid double counting.

C. Notation

We define the notation here and use it consistently throughout the paper. We index the $N = 36$ issuer countries as $n = 1, \ldots, N$. Within each country, there are three asset classes: 1) short-term debt, 2) long-term debt, and 3) equity. We index the three asset classes as $l = 1, 2, 3$. $P_t(n, l)$ is the market-to-book ratio for asset class l in country n at time t. $Q_t(n, l)$ is the total book value in country n's currency unit of asset class l in country n at time t.

In the case of debt, $P_t(n,l)$ is the price per unit of face value, and $Q_t(n,l)$ is the total face value in local currency unit. We refer to $P_t(n,l)$ and $Q_t(n,l)$ as the price and quantity of asset class l in country n, respectively. $E_t(n)$ is the nominal exchange rate in US dollars per country n's currency unit at time t. $Z_t(n)$ is the US consumer price index (CPI) in dollars relative to country n's CPI in its currency unit. Thus, $E_t(n)/Z_t(n)$ is the real exchange rate.

To clarify the notation, consider an example of UK long-term debt. $P_t(n,2)$ is the market price in pounds per pound of face value (or equivalently, in US dollars per dollar of face value). $Q_t(n,2)$ is the total face value of debt in pounds. $E_t(n)$ is the exchange rate in US dollars per pound. Thus, $P_t(n,2)Q_t(n,2)$ is the total market value of debt in pounds, and $P_t(n,2)E_t(n)Q_t(n,2)$ is the total market value of debt in US dollars.

We use lowercase letters to denote the logarithm of the corresponding uppercase variables. For example, $p_t(n,l) = \log(P_t(n,l))$, $q_t(n,l) = \log(Q_t(n,l))$, $e_t(n) = \log(E_t(n))$, and $z_t(n) = \log(Z_t(n))$. We use bold letters to denote column vectors or matrices, whose elements are the corresponding variables. For example, $\mathbf{P}_t$ is a matrix whose (n,l)th element is $P_t(n,l)$, and $\mathbf{E}_t$ is a column vector whose nth element is $E_t(n)$.

D. Relative Asset Quantities and Prices

Figure 1 is a scatter plot of relative long-term debt quantity versus price for the euro area, Japan, Switzerland, and the UK. The horizontal axis measures each region's long-term debt quantity relative to the US in logarithms (i.e., $q_t(n,2)-q_t(\mathrm{US},2)$). The vertical axis measures each region's long-term bond price in US dollars relative to the US long-term bond price in logarithms (i.e., $p_t(n,2)+e_t(n)-p_t(\mathrm{US},2)$). We subtract the time-series mean so that both relative quantities and prices are in percent deviation (i.e., 0.2 means 20% higher than the average year). The scatter plot reveals a negative relation that is consistent with a downward-sloping demand curve. When the supply of Japanese long-term debt is relatively high, its relative price is low. Our finding suggests a downward-sloping demand for long-term debt, extending a similar finding for the US to an international context (Krishnamurthy and Vissing-Jørgensen 2012; Greenwood and Vayanos 2014).

Figure 2 repeats the same exercise for equity markets. The horizontal axis measures each region's equity quantity relative to the US in logarithms (i.e., $q_t(n,3)-q_t(\mathrm{US},3)$). The vertical axis measures each region's stock price in US dollars relative to the US stock price in logarithms (i.e., $p_t(n,3)+e_t(n)-p_t(\mathrm{US},3)$). Again, the scatter plot reveals a negative relation that is consistent with a downward-sloping demand curve. When the supply of Japanese equity is relatively high, its relative price is low.

Figures 1 and 2 are by no means formal estimates of demand curves, which we leave for Section III. However, they foreshadow estimates of low demand elasticities for long-term debt and equity. The slope of the demand curve reveals 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 and 2 suggests that long-term debt and equity of different countries are imperfect substitutes.

II. Demand System Asset Pricing

We present an asset demand system that matches observed international holdings and implies flexible substitution within and across asset classes. We also discuss how the asset demand system and market clearing determine exchange rates and asset prices. In Appendix B, we show that the demand system approach collapses to the capital asset pricing model (CAPM) when investors are homogeneous and have identical portfolios.

A. Market Clearing

There are I investor countries that we index as $i = 1, \ldots, I$. Each investor i allocates wealth $A_{i,t}$ in US dollars at time t across three asset classes in N issuer countries. The investor could also allocate wealth to countries outside the N issuer countries, which we represent as an outside asset (indexed as $n = 0$) within each asset class. Without loss of generality, we write investor i's portfolio weight in country n and asset class l at time t as

$$w_{i,t}(n, l) = w_{i,t}(n|l)w_{i,t}(l). \tag{1}$$

The first term on the right side represents the portfolio weight in country n within asset class l. The second term represents the aggregate portfolio weight in asset class l.

The portfolio weights must sum to one within each asset class: $\sum_{n=0}^{N} w_{i,t}(n|l) = 1$. The aggregate portfolio weights must also sum to one across all asset classes: $\sum_{l=1}^{3} w_{i,t}(l) = 1$. Let $O_{i,t} = \sum_{l=1}^{3} A_{i,t}w_{i,t}(0, l)$ be the total investment in outside assets across all asset classes. We write the investor's wealth as

$$A_{i,t} = \frac{O_{i,t}}{1 - \sum_{l=1}^{3} \sum_{n=1}^{N} w_{i,t}(n, l)}. \tag{2}$$

Market clearing for each country n and asset class l at time t is

$$P_t(n,l)E_t(n)Q_t(n,l) = \sum_{i=1}^{I} A_{i,t} w_{i,t}(n,l;\mathbf{P}_t,\mathbf{E}_t)$$
$$= \sum_{i=1}^{I} \frac{O_{i,t} w_{i,t}(n,l;\mathbf{P}_t,\mathbf{E}_t)}{1-\sum_{k=1}^{3}\sum_{m=1}^{N} w_{i,t}(m,k;\mathbf{P}_t,\mathbf{E}_t)}. \tag{3}$$

The left side is supply. The right side is demand, which is wealth times the portfolio weight aggregated across all investors. The notation in equation (3) emphasizes that both wealth and the portfolio weights depend on the entire vector of exchange rates and asset prices.

Market clearing is a system of $3N$ equations in $3N$ asset prices and $N-1$ exchange rates. By defining all exchange rates to be US dollars per local currency unit, we normalize the exchange rate for the US to be one. Conditional on realized short-term bond prices (or equivalently, short-term rates), we have a system of $3N$ equations in N long-term bond prices, N stock prices, and $N-1$ exchange rates. We obtain an exactly determined system by assuming that the Federal Reserve adjusts the supply so that the US short-term debt market clears at a given short-term rate. Therefore, we could use the demand system (3) as an international asset pricing model once we specify a model of portfolio weights.

B. Characteristics-Based Demand

Koijen and Yogo (2019) develop a characteristics-based model of asset demand, in which the portfolio weights are a logit function of asset prices, asset characteristics, and latent demand. The logit function implies portfolio weights that are strictly positive and sum to one. The exponential-linear specification is ideal for fitting observed holdings that are log-normally distributed. The presence of latent demand makes the model sufficiently flexible to match actual holdings.

Koijen and Yogo (2019) derive characteristics-based demand from the mean-variance portfolio, which is the solution of a portfolio choice problem. The key assumptions are that returns have a factor structure and that expected returns and factor loadings depend on the assets' own characteristics. These assumptions make an asset's own characteristics sufficient for its contribution to the expected return and risk of the overall portfolio. We refer to Appendix B for further details about the relation between characteristics-based demand and the mean-variance portfolio.

We extend the demand specification of Koijen and Yogo (2019) in two ways to tailor to the present context of international holdings across three asset classes. First, asset demand depends on both exchange rates and asset prices. We model portfolio weights as a function of expected returns through a predictive regression of returns onto the market-to-book ratio and the real exchange rate. Second, we use a nested logit specification to allow for imperfect substitution across asset classes. The inner nest $w_{i,t}(n|l)$ in equation (1) describes how an investor substitutes across countries within an asset class. The outer nest $w_{i,t}(l)$ describes how an investor substitutes across asset classes.

Expected returns

We model how expected returns are related to exchange rates and asset prices through a predictive regression. Let $r_{t+1}(n,l)$ be the continuously compounded return in US dollars for asset class l in country n from year t to $t+1$. Let $y_t(n)$ be country n's continuously compounded 1-year yield in year t, where $y_t(\text{US})$ is the US yield. Let $\Delta e_{t+1}(n)$ be the change in log exchange rate from year t to $t+1$. The predictor variables are log market-to-book $p_t(n,l)$ and log real exchange rate $e_t(n) - z_t(n)$. For debt, log market-to-book is minus maturity times the continuously compounded yield. For equity, log market-to-book is a valuation measure, for which high valuation predicts subsequently low returns.

Separately for each asset class, we define a panel regression model for excess returns:

$$r_{t+1}(n,l) - y_t(\text{US}) = \phi_l p_t(n,l) + \psi_l(e_t(n) - z_t(n)) + \chi_{n,l} + \nu_{t+1}(n,l), \tag{4}$$

where $\chi_{n,l}$ are country by asset class fixed effects. The return in US dollars is the sum of the return in local currency unit plus the change in log exchange rate. A high real exchange rate predicts depreciation of the nominal exchange rate under purchasing power parity. Therefore, the real exchange rate should predict foreign returns in US dollars.

We assume that investors care about returns in their own currency unit for the purposes of portfolio choice. The predicted values from panel regression (4) imply expected returns in US dollars. We construct expected returns in investor i's currency unit based on

$$\begin{aligned}\mathbb{E}_t[r_{t+1}(n,l) - \Delta e_{t+1}(i) - y_t(i)] =& \mathbb{E}_t[r_{t+1}(n,l) - r_{t+1}(i,1)] \\ =& \mu_{i,t}(n,l) + \chi_{n,l} - \chi_{i,1},\end{aligned} \tag{5}$$

where

$$\mu_{i,t}(n,l) = \phi_l p_t(n,l) + \psi_l(e_t(n) - z_t(n)) - \phi_1 p_t(i,1) - \psi_1(e_t(i) - z_t(i)). \tag{6}$$

Consider an example of Japanese investors holding UK equity, who care about returns in yen. The left side of equation (5) is the expected excess UK stock return in yen relative to the Japanese short-term rate. The right side says that this expected excess return is equivalent to the expected UK stock return in US dollars minus the expected Japanese short-term bond return in US dollars.

Allocation within Asset Class

We model the portfolio weight in country n within asset class l at time t as

$$w_{i,t}(n|l) = \frac{\delta_{i,t}(n,l)}{1 + \sum_{m=0}^{N} \delta_{i,t}(m,l)}, \tag{7}$$

where

$$\delta_{i,t}(n,l) = \exp\{\beta_l \mu_{i,t}(n,l) + \Theta_l' \mathbf{x}_{i,t}(n) + \epsilon_{i,t}(n,l)\}. \tag{8}$$

Demand depends on the expected return $\mu_{i,t}(n,l)$, a vector of asset characteristics $\mathbf{x}_{i,t}(n)$, and latent demand $\epsilon_{i,t}(n,l)$. We index the coefficients β_l and Θ_l by l to allow for heterogeneous demand elasticities across asset classes.[3] By the budget constraint, the portfolio weight in the outside asset within asset class l at time t is

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

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

We index the asset characteristics not only by issuer n but also by investor i to allow for bilateral variables such as export shares, import shares, and distance. Thus, perceived risk for the same asset could vary across investors. For example, investors could perceive farther countries as having higher risk because of informational frictions that increase with distance. Similarly, latent demand represents characteristics unobserved by the econometrician, which capture differences in expected returns and perceived risk across investors and assets.

[3] In the logit case, the coefficient restriction $\beta_l > \max\{1/\phi_l, 1/\psi_l\}$ is sufficient for existence and uniqueness of equilibrium (Koijen and Yogo 2019, Proposition 2).

Allocation across Asset Classes

We model the aggregate portfolio weight in asset class l at time t as

$$\widehat{w}_{i,t}(l) = \frac{\left(1 + \sum_{m=0}^{N} \delta_{i,t}(m,l)\right)^{\lambda_l} \exp\{\alpha_l + \xi_{i,t}(l)\}}{\sum_{k=1}^{3} \left(1 + \sum_{m=0}^{N} \delta_{i,t}(m,k)\right)^{\lambda_k} \exp\{\alpha_k + \xi_{i,t}(k)\}}, \tag{10}$$

where $\lambda_l \in [0, 1]$. The first term inside the parentheses in the numerator, which is also the denominator in the inner nest (7), is called the "inclusive value" in a nested logit model. To understand the role of the inclusive value, suppose that the coefficient on the short-term bond price is negative (i.e., $\beta_1 < 0$). A decrease in short-term bond prices across several countries makes short-term debt more attractive as an asset class, reflected by an increase in the inclusive value of short-term debt. The outer nest (10) then implies an increase in the aggregate portfolio weight in short-term debt. Thus, the inclusive value connects changing asset prices and characteristics in the inner nest to respective changes in portfolio weights in the outer nest.

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 represents characteristics unobserved by the econometrician, which capture differences in expected returns and perceived risk across investors and asset classes. Because the budget constraint implies that there are only two degrees of freedom, we normalize $\alpha_3 + \xi_{i,t}(3) = 0$ for equity.

By market clearing (3), a demand shock in one asset class could affect prices in other asset classes through two channels. The first channel is a substitution effect. A demand shock could change the inclusive value of an asset class and thereby change the aggregate portfolio weights (10) across asset classes. The second channel is a wealth effect. A demand shock could change the investors' wealth (2), which affects the demand for other asset classes. As we discussed above, market clearing across all asset classes determines exchange rates, conditional on short-term rates. Thus, a demand shock in long-term debt or equity markets could affect exchange rates through both substitution and wealth effects.

Special Cases

When $\lambda_l = 1$ for all asset classes in equation (10), the portfolio weight simplifies to the logit specification (Koijen and Yogo 2019):

$$w_{i,t}(n,l) = \frac{\delta_{i,t}(n,l)}{3 + \sum_{k=1}^{3} \sum_{m=0}^{N} \delta_{i,t}(m,k)}. \tag{11}$$

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

When $\lambda_l = 0$ for all asset classes in equation (10), the portfolio weight simplifies to

$$w_{i,t}(n,l) = \frac{\delta_{i,t}(n,l)}{1 + \sum_{m=0}^{N} \delta_{i,t}(m,l)} \frac{\exp\{\alpha_l + \xi_{i,t}(l)\}}{\sum_{k=1}^{3} \exp\{\alpha_k + \xi_{i,t}(k)\}}. \tag{12}$$

In this case, the allocation across asset classes does not depend on the inclusive value. As we discussed above, this means that only wealth effects are present and not substitution effects. Blanchard, Giavazzi, and Sa (2005) emphasize this special case. Although the overall allocation to equity is constant, the allocation across countries within equity affects exchange rates through the wealth effect.

These two cases clarify that λ_l is an important parameter that determines the strength of substitution across asset classes. Higher values of λ_l imply stronger substitution across asset classes. That is, a demand shock has stronger effects on prices in other asset classes.

III. Demand Estimation

We discuss the identifying assumption, describe the estimation procedure, and present the estimated demand system.

A. *Estimating Equations*

Demand within Asset Class

Dividing equation (7) by equation (9) and taking the logarithm, we have

$$\log\left(\frac{w_{i,t}(n|l)}{w_{i,t}(0|l)}\right) = \beta_l \mu_{i,t}(n,l) + \Theta_l' \mathbf{x}_{i,t}(n) + \epsilon_{i,t}(n,l). \tag{13}$$

This is a separate panel regression model for each asset class l, whose observations are investor i's holding of country n in year t. Equation (13) says that the demand for Japanese long-term debt relative to UK long-term debt depends on their relative characteristics. An investor substitutes from Japanese to UK long-term debt if the characteristics of UK long-term debt become relatively more attractive (e.g., higher rating).

The coefficients β_l and Θ_l vary across asset classes. However, they do not vary across investors because of the limited sample size in our data at the country level. Koijen et al. (2018) allow the coefficients to vary across investor types using more disaggregate data at the institution level for sovereign debt in the euro area.

Demand across Asset Classes

Dividing equation (10) for short- or long-term debt (i.e., $l = 1, 2$) by the same equation for equity (i.e., $l = 3$) and taking the logarithm, we have

$$\begin{aligned}\log\left(\frac{w_{i,t}(l)}{w_{i,t}(3)}\right) =& \lambda_l \log\left(1 + \sum_{m=0}^{N} \delta_{i,t}(m,l)\right) - \lambda_3 \log\left(1 + \sum_{m=0}^{N} \delta_{i,t}(m,3)\right) + \alpha_l + \xi_{i,t}(l) \\ =& -\lambda_l \log(w_{i,t}(0|l)) + \lambda_3 \log(w_{i,t}(0|3)) + \alpha_l + \xi_{i,t}(l). \end{aligned} \tag{14}$$

The second line follows from equation (9), which relates the inclusive value to the portfolio weight in the outside asset. This is a panel regression model, whose observations are investor i's aggregate holding of asset class l relative to equity in year t. Equation (14) says that the demand for short-term debt relative to equity depends on their relative inclusive value. An investor substitutes from short-term debt to equity if the characteristics of equity become relatively more attractive (e.g., lower prices).

B. Asset Characteristics

To operationalize equation (13), we must specify asset characteristics that explain portfolio choice across countries. The macro variables are log nominal GDP, log real GDP per capita, and inflation. The risk measures are equity volatility and sovereign debt ratings. We convert the rating to a continuous measure equal to minus one times the 5-year default probability, so that a higher measure implies a higher rating. Bilateral variables are the export share, the import share, and distance. We refer to Appendix A for further details about how we construct these variables.

We include investor fixed effects to allow for cross-sectional variation in the outside asset weight. We include year fixed effects to allow for time-series variation in the outside asset weight. The combination of investor and year fixed effects means that the variation across issuer countries (rather than the variation between inside and outside assets) identifies the demand elasticities. For all asset classes, we include fixed effects for US issuance interacted with year. These fixed effects capture the special status of US assets that is time varying. For the equity market, we capture home bias through a dummy for own country ownership.

C. Identifying Assumption

Demand estimation requires an identifying assumption because latent demand is jointly endogenous with exchange rates and asset prices. Our starting point is the assumption that asset characteristics and quantities are exogenous in the same spirit as asset pricing in endowment economies (Lucas 1978) or term structure models with an exogenous short-term rate (Cox, Ingersoll, and Ross 1985). The ultimate goal, beyond the scope of this paper, is to endogenize the macro variables together with exchange rates and asset prices. Doing so for all 36 countries is a formidable task that is beyond the scope of current international macro models (Engel and Matsumoto 2009; Devereux and Sutherland 2011; Heathcote and Perri 2013).

We also assume that the total investment in outside assets is exogenous. That is, the initial distribution of wealth across investor countries prior to portfolio choice is predetermined and exogenous to current latent demand. Let $\mathbf{x}_t$ be a matrix of asset characteristics for all investor countries, issuer countries, and asset classes. Let $\mathbf{Q}_t$ be a matrix of asset quantities for all issuer countries and asset classes. Let $\mathbf{O}_t$ be a vector of investment in outside assets for all investor countries. Formally, the identifying assumption amounts to a conditional moment restriction:

$$\mathbb{E}\left[\begin{array}{c} \epsilon_{i,t}(n,l) \\ \xi_{i,t}(l) \end{array} \middle| \mathbf{x}_t, \mathbf{Q}_t, \mathbf{O}_t\right] = \mathbf{0}. \tag{15}$$

In typical economic applications, equation (15) is not sufficient for identification because we do not have an explicit instrument. In our case, we have an implicit instrument that depends only on asset characteristics through market clearing. In equation (13), the demand for Japanese long-term debt depends directly on its own characteristics and indirectly on the characteristics of other countries' long-term debt through exchange rates and asset prices. For example, when the characteristics of UK long-term debt become relatively more attractive, the relative demand for Japanese long-term debt falls through market clearing. Under equation (15), market clearing defines a particular nonlinear function of all asset characteristics as an instrument for exchange rates and asset prices. We now describe how to construct the instrument in the context of a step-by-step description of the estimation procedure.

D. Estimation Procedure

The estimation proceeds in four steps. In the first step, we estimate the predictive regression (4). We then construct expected returns (6), which we will use in the fourth step to estimate demand within asset class through equation (13).

In the second step, we estimate a reduced-form regression corresponding to equation (13):

$$\log\left(\frac{w_{i,t}(n|l)}{w_{i,t}(0|l)}\right) = \pi_l' \mathbf{x}_{i,t}(n) + \eta_{i,t}(n,l). \tag{16}$$

Let $\widehat{\delta}_{i,t}(n,l)$ be the predicted value of this regression, which is a function of only the asset characteristics. We will use this predicted demand to construct the instrument in the following steps.

Demand across Asset Classes

In the third step, we estimate demand across asset classes through equation (14), in which the two endogenous regressors are the logarithms of $w_{i,t}(0|l)$ and $w_{i,t}(0|3)$. We construct an instrument for $w_{i,t}(0|l)$:

$$\widehat{w}_{i,t}(0|l) = \frac{1}{1 + \sum_{m=0}^{N} \widehat{\delta}_{i,t}(m,l)}. \tag{17}$$

We estimate instrumental variables regression (14) with two instruments, which are $\log(\widehat{w}_{i,t}(0|l))$ and $\log(\widehat{w}_{i,t}(0|3))$. In the following step, we will denote the estimated coefficients for demand across asset classes as $\widehat{\lambda}_l$ and $\widehat{\alpha}_l$.

Demand within Asset Class

We construct a predicted weight in country n and asset class l at time t:

$$\widehat{w}_{i,t}(n,l) = \frac{\widehat{\delta}_{i,t}(n,l)}{1 + \sum_{m=0}^{N} \widehat{\delta}_{i,t}(m,l)} \frac{\left(1 + \sum_{m=0}^{N} \widehat{\delta}_{i,t}(m,l)\right)^{\widehat{\lambda}_l} \exp\{\widehat{\alpha}_l\}}{\sum_{k=1}^{3} \left(1 + \sum_{m=0}^{N} \widehat{\delta}_{i,t}(m,k)\right)^{\widehat{\lambda}_k} \exp\{\widehat{\alpha}_k\}}. \tag{18}$$

These predicted weights capture the exogenous part of portfolio weights that depend only on asset characteristics. We then compute counterfactual exchange rates and asset prices that clear markets at the predicted weights. The instrument for the exchange rate clears the short-term debt market at the predicted weights:

$$\widehat{E}_t(n) = \frac{1}{Q_t(n,1)} \sum_{i=1}^{I} \frac{O_{i,t}\widehat{w}_{i,t}(n,1)}{1 - \sum_{k=1}^{3} \sum_{m=1}^{N} \widehat{w}_{i,t}(m,k)}. \tag{19}$$

The instruments for the long-term bond price ($l = 2$) and the stock price ($l = 3$) clear their respective markets at the predicted weights:

$$\widehat{P}_t(n,l) = \frac{1}{\widehat{E}_t(n)Q_t(n,l)} \sum_{i=1}^{I} \frac{O_{i,t}\widehat{w}_{i,t}(n,l)}{1 - \sum_{k=1}^{3} \sum_{m=1}^{N} \widehat{w}_{i,t}(m,k)}. \tag{20}$$

In constructing the instrument for equity, we exclude own country holdings from both sides of market clearing to avoid the instrument being dominated by the strong home bias.

In the fourth step, we estimate demand within asset class through equation (13), in which the endogenous regressor is the expected return $\mu_{i,t}(n,l)$. For short-term debt, we estimate instrumental variables regression (13) with $\log(\widehat{E}_t(n))$ as the instrument for the expected return. For long-term debt, we use $\log(\widehat{P}_t(n,2))$ and $\log(\widehat{E}_t(n))$ as instruments for the expected return. For equity, we use $\log(\widehat{P}_t(n,3))$ and $\log(\widehat{E}_t(n))$ as instruments for the expected return.

Having described the estimation procedure mechanically, we now offer a simpler version of the instrument and explain the intuition behind identification. For estimating equation (13), we only need cross-sectional variation in asset prices and the instruments. Therefore, we could construct a strong instrument based only on a small subset of asset characteristics that are slow moving or time invariant: log GDP, distance, investor fixed effects, and a dummy for own country ownership. In this simpler version, variation in the instrument arises only from the size distribution of investor countries (captured by $O_{i,t}$), the size distribution of issuer countries (captured by log GDP and asset quantities), and the distance between and investor and issuer countries. Relatively small issuer countries that are in close proximity to relatively large investor countries have a high inelastic component of demand, and consequently, high exchange rates and asset prices.

The estimates are ultimately not sensitive to whether or not we use the simpler version of the instrument. However, we prefer the simpler version because the source of variation that the instrument is exploiting has a clear interpretation. Therefore, we present estimates for the simpler version in the remainder of the paper.

E. Estimated Demand System

Expected returns

Table 3 reports estimates of panel regression (4) for short-term debt, long-term debt, and equity across 36 countries from 2002 to 2017. Log market-to-book and log real exchange rate are reliable predictors of excess returns for all asset classes. For short-term debt, the estimated coefficient is −7.78 on log market-to-book and −0.31 on log real exchange rate. For long-term debt, the estimated coefficient is −0.45 on log market-to-book and −0.37 on log real exchange rate. For equity, the estimated coefficient is −0.29 on log market-to-book and −0.88 on log real exchange rate. These coefficients imply that expected stock returns increase by 29 basis points per one percent decrease in market-to-book equity and 88 basis points per one percent increase in the real exchange rate.

Demand within Asset Class

Table 4 reports the estimated coefficients for demand within asset class. The coefficient on the expected return is 31.53 for short-term debt. Although there is no simple analytic expression for the demand elasticity, we numerically compute the partial derivative to be 42 in 2017. That is, short-term debt demand decreases by 42 percent per one percent price increase. With a maturity of 0.25 years, the demand elasticity with respect to yield is 10.5. That is, short-term debt demand decreases by 10.5 percent per one percentage point yield decrease. The coefficient on the expected return is 9.31 for long-term debt, which implies a demand elasticity of 4.2 in 2017. With a maturity of 10 years, the demand elasticity with respect to yield is 42. The coefficient on the expected return is 4.29 for equity, which implies a demand elasticity of 1.9 in 2017.

The signs of the coefficients on the macro variables are similar across asset classes. The coefficients on log GDP and log GDP per capita are positive, which means that demand increases with the issuer country's size and wealth. Demand decreases in inflation, especially for short- and long-term debt. Long-term debt demand decreases by 22 percent per one percentage point increase in inflation.

Demand decreases in the two risk measures across all asset classes. The coefficient on equity volatility is -4.83 for equity, which means that demand decreases by 4.83 percent per one percentage point increase in equity volatility. The coefficient on sovereign debt rating is 0.23 for long-term debt, which means that demand decreases by 23 percent per one percentage point increase in the 5-year default probability.

The bilateral variables are highly significant determinants of demand across all asset classes. The coefficients on export and import shares are positive and significant, except for the import share being insignificant for short-term debt. That is, investors hold assets of countries with which they trade more (Lane and Milesi-Ferretti 2008). The coefficient on the export share is 0.32 for equity, which means that demand increases by 32 percent per one percentage point increase in exports as a share of the geometric average of GDP. Even after controlling for trade activity, distance is a highly significant determinant of demand. The coefficient on distance is -0.11 for equity, which means that demand decreases by 11 percent per 1,000 km increase in distance. Although there are several potential explanations, the previous literature favors the hypothesis that informational frictions increase with distance (Portes, Rey, and Oh 2001; Portes and Rey 2005).

In addition to local bias, there is a strong home bias in the equity market. The coefficient on the dummy for own country ownership is 7.21. That is, demand for own equity is seven times higher than that for foreign equity, controlling for asset characteristics.

Demand across Asset Classes

Table 5 reports estimated coefficients for demand across asset classes. The coefficient on log outside asset weight is $\lambda_1 = 0.23$ for short-term debt, $\lambda_2 = 0.24$ for long-term debt, and $\lambda_3 = 0.50$ for equity. For all asset classes, we reject the hypothesis that the coefficient is zero. This means that substitution across asset classes is important for exchange rates and asset prices.

IV. Decomposition of Exchange Rates and Asset Prices

Based on the estimated demand system and market clearing, we decompose exchange rates and asset prices into five sources of variation. They are changes in macro variables, short-term rates, long-term debt quantities, foreign exchange reserves, and latent demand. We also present a case study of the European sovereign debt crisis.

The variance decomposition in this section is an accounting exercise based on market clearing and an econometric model of portfolio weights. It is in the same spirit as a variance decomposition of the price-dividend ratio based on a present-value identity and an econometric model of stock price and dividend dynamics (Campbell and Shiller 1988). Neither our variance decomposition nor Campbell and Shiller (1988) can be interpreted as causal effects that would arise from a fully specified macro model. Nevertheless, these variance decompositions are useful for isolating important sources of variation to estimate and test existing macro models and to help design future models.

A. Market Clearing

In our empirical implementation, we have market clearing (3) for long-term debt and equity across 36 countries. For the short-term debt market, we only have 27 market clearing equations because 10 of the 36 countries have a common short-term rate in the euro area. Because all exchange rates are defined in US dollars per local currency unit, the exchange rate for the US is always one. In the counterfactual experiments, we assume that the Federal Reserve adjusts the supply so that the US short-term debt market clears at a given short-term rate (and an exchange rate of one). Similarly, the Hong Kong dollar is pegged to the US dollar, and the Danish krone is pegged to the euro. We assume that the respective central banks maintain their currency pegs in counterfactual experiments. That is, the central bank adjusts the supply so that its short-term debt market clears at a given short-term rate and currency peg.

Market clearing defines an implicit function for exchange rates and asset prices, which we express as

$$\begin{bmatrix} \mathbf{e}_t \\ \mathbf{p}_t(2) \\ \mathbf{p}_t(3) \end{bmatrix} = \mathbf{g}(\mathbf{x}_t, \mathbf{z}_t, \mathbf{O}_t, \mathbf{p}_t(1), \mathbf{Q}_t, \epsilon_t, \xi_t). \tag{21}$$

The left side is a vector of exchange rates, long-term bond prices, and market-to-book equity. The right side is a function of asset characteristics, relative CPI, outside assets, short-term bond prices, asset quantities, latent demand, and asset-class latent demand.

We order and group the variables on the right side of equation (21) as follows.

1. Macro variables: $\mathbf{x}_t$, $\mathbf{z}_t$, $\mathbf{O}_t$, and $\mathbf{Q}_t(3)$.

2. Short-term rates: $\mathbf{p}_t(1)$ and $\mathbf{Q}_t(1)$.

3. Long-term debt quantities: $\mathbf{Q}_t(2)$.

4. Foreign exchange reserves: Submatrix of ϵ_t and ξ_t for foreign exchange reserves only.

5. Latent demand: Submatrix of ϵ_t and ξ_t for investor countries.

Macro variables are a set of variables that government policy does not determine directly and would evolve exogenously in an endowment economy. Central bank policy determines short-term rates together with short-term debt quantities. Fiscal policy and unconventional monetary policy determine long-term debt quantities. We separate latent demand into that of foreign exchange reserves, determined by central bank policy, and investor countries.

B. Variance Decomposition of Exchange Rates and Asset Prices

We change the macro variables in equation (21) from their values in year t to $t+1$ and compute the counterfactual vector of exchange rates and asset prices that would clear all markets. Using the subscript 1, we denote the counterfactual exchanges rates as $\mathbf{e}_{1,t+1}$, long-term bond prices as $\mathbf{p}_{1,t+1}(2)$, and market-to-book equity as $\mathbf{p}_{1,t+1}(3)$. We repeat the same procedure for short-term rates and denote the counterfactual exchanges rates and asset prices using the subscript 2: $\mathbf{e}_{2,t+1}$, $\mathbf{p}_{2,t+1}(2)$, and $\mathbf{p}_{2,t+1}(3)$. We repeat the same procedure for long-term debt quantities (using the subscript 3), foreign exchange reserves (using the subscript 4), and latent demand (using the subscript 5). The actual realized change in exchange rates from year t to $t+1$ is the sum of the changes across these counterfactual experiments:

$$\begin{aligned} \mathbf{e}_{t+1} - \mathbf{e}_t =& \mathbf{e}_{1,t+1} - \mathbf{e}_t + \mathbf{e}_{2,t+1} - \mathbf{e}_{1,t+1} + \mathbf{e}_{3,t+1} - \mathbf{e}_{2,t+1} + \mathbf{e}_{4,t+1} - \mathbf{e}_{3,t+1} \\ &+ \mathbf{e}_{5,t+1} - \mathbf{e}_{4,t+1}, \end{aligned} \tag{22}$$

Thus, we have a variance decomposition of annual changes in exchange rates:

$$\begin{aligned}\mathrm{Var}(\mathbf{e}_{t+1}-\mathbf{e}_t) =&\mathrm{Cov}(\mathbf{e}_{1,t+1}-\mathbf{e}_t,\mathbf{e}_{t+1}-\mathbf{e}_t)+\mathrm{Cov}(\mathbf{e}_{2,t+1}-\mathbf{e}_{1,t+1},\mathbf{e}_{t+1}-\mathbf{e}_t)\\ &+\mathrm{Cov}(\mathbf{e}_{3,t+1}-\mathbf{e}_{2,t+1},\mathbf{e}_{t+1}-\mathbf{e}_t)+\mathrm{Cov}(\mathbf{e}_{4,t+1}-\mathbf{e}_{3,t+1},\mathbf{e}_{t+1}-\mathbf{e}_t)\\ &+\mathrm{Cov}(\mathbf{e}_{5,t+1}-\mathbf{e}_{4,t+1},\mathbf{e}_{t+1}-\mathbf{e}_t).\end{aligned} \tag{23}$$

We define the variance decomposition of long-term bond prices and market-to-book equity analogously.

Table 6 reports the variance decomposition of exchange rates, weighted by 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. Macro variables account for 26 percent, short-term rates account for 8 percent, long-term debt quantities account for 2 percent, and foreign exchange reserves account for 19 percent of the variation in exchange rates. These fundamental sources jointly account for 55 percent of the variation in exchange rates. Latent demand, which is uncorrelated with asset characteristics in the demand specification, accounts for the remaining 45 percent.

In Table 7, we further decompose the contribution of latent demand to the variance of exchange rates by geographic group and asset class. Recall from Table 2 that a significant amount of short-term debt investment passes through offshore financial centers (i.e., Ireland, Luxembourg, and the Cayman Islands). Consistent with this fact, latent demand of offshore financial centers substituting across short-term debt markets accounts for 26 percent of the variation in exchange rates. Developed countries in North America and Europe are large investors across all asset classes. Consequently, asset-class latent demand of North American and European investors, which captures substitution across asset classes, each accounts for 8 percent of the variation in exchange rates. Hau and Rey (2004) and Camanho, Hau, and Rey (2018) also find that substitution across asset classes is important for exchange rates. A key takeaway of Table 7 is that the importance of latent demand is geographically concentrated in large investor countries.

Table 6 reports the variance decomposition of long-term yields, weighted by size of the long-term debt market. Although macro variables account for 16 percent of the variation in long-term yields, policy variables play a more important role. Short-term rates account for 9 percent, and long-term debt quantities account for 20 percent of the variation in long-term yields. Foreign exchange reserves account for 11 percent of the variation in long-term yields, confirming the importance of central bank interventions in foreign debt markets. Latent demand accounts for 43 percent of the variation in long-term yields, of which European investors account for 28 percent.

Table 6 also reports the variance decomposition of market-to-book equity, weighted by size of the equity market. Macro variables and short-term rates are the primary determinants of market-to-book equity. Macro variables account for 57 percent, and short-term rates account for 6 percent of the variation in market-to-book equity. Latent demand accounts for 31 percent of the variation in market-to-book equity. European and Pacific investors each account for 13 and 11 percent of the variation in market-to-book equity, respectively.

As a point of reference, Table C1 in Appendix C reports reduced-form regressions of annual changes in exchange rates and asset prices onto contemporaneous changes in the macro variables. We obtain an R^2 of 44 percent for exchange rates, 46 percent for long-term yields, and 55 percent for market-to-book equity. Other studies have also confirmed high explanatory power in the post-crisis sample in contrast to no explanatory power in the pre-crisis sample (Engel and Wu 2018; Lilley et al. 2019). Therefore, it should not be surprising that fundamentals have high explanatory power in Table 6. The problem with the reduced-form regressions in Table C1 is that the signs of the estimated coefficients are inconsistent across asset classes and difficult to interpret. In contrast, the estimated coefficients for demand in Table 4 have an intuitive economic interpretation, and their signs are consistent across asset classes.

C. A Closer Examination of the Variance Decomposition

According to the second step of the variance decomposition in Table 6, short-term rates account for 8 percent of the variation in exchange rates. This estimate represents the average relation across countries and over time. To better understand the sources of variation that lead to this estimate, Figure 3 reports the realized changes in exchange rates that relate to contemporaneous changes in short-term rates for four regions: the euro area, Japan, Switzerland, and the UK. That is, the vertical axis reports the subvector of $\mathbf{e}_{2,t+1} - \mathbf{e}_{1,t+1}$ in equation (22) that corresponds to the four regions, and the horizontal axis reports the corresponding change in the short-term rate. In all four regions, monetary easing is associated with a depreciation of the exchange rate. Averaged across the four regions, the exchange rate depreciates by 2.2 percent per one percentage point decrease in the short-term rate.

According to the third step of the variance decomposition, long-term debt quantities account for 2 percent of the variation in exchange rates and 20 percent of the variation in long-term yields. Figure 4 takes a closer examination of the third step of the variance decomposition for the four regions. The horizontal axis reports annual changes in long-term yields that relate to contemporaneous changes in long-term debt quantities (i.e., $-10(\mathbf{p}_{3,t+1}(2) - \mathbf{p}_{2,t+1}(2))$ assuming a 10-year maturity). The vertical axis reports annual changes in exchange rates that relate to contemporaneous changes in long-term debt quantities (i.e., $\mathbf{e}_{3,t+1} - \mathbf{e}_{2,t+1}$). In all four regions, a decrease in long-term debt quantity is associated with a lower long-term yield and a depreciation of the exchange rate. Averaged across the four regions, a change in long-term debt quantity that decreases the long-term yield by one percentage point also depreciates the exchange rate by 1.5 percent.

D. A Case Study of the European Sovereign Debt Crisis

We demonstrate that the variance decomposition could be used to interpret major economic events through a case study of the European sovereign debt crisis. Table 8 reports the variance decomposition of the long-term yield spread between Germany and the US. Short-term rates account for 53 percent, long-term debt quantities account for 15 percent, and foreign exchange reserves account for 20 percent of the variation in the long-term yield spread. Remarkably, these policy variables together account for 88 of the variation in the long-term yield spread.

Figure C1 in Appendix C is a simple scatter plot that explains this finding. The upper panel shows that the long-term yield spread between Germany and the US is positively related to the interest rate differential between the two countries. That is, the relative level factor drives the long-term yield spread. The lower panel shows that the long-term yield spread is positively related to the relative long-term debt quantity. In both scatter plots, the data points in the upper right are 2002, 2003, and 2008 when the US had relatively expansionary monetary policy and a lower long-term yield. The data points in the lower left are 2016 and 2017 when Germany had relatively expansionary monetary policy and a lower long-term yield.

Table 8 also reports the variance decomposition of the long-term yield spreads between southern euro countries (i.e., Greece, Italy, and Portugal) and Germany. Because countries in the euro area share a common short-term rate, the variance decomposition gives a sensible answer that short-term rates account for none of the variation in the long-term yield spreads. Especially after 2008, southern euro countries had very different macro and fiscal experiences relative to Germany. Consistent with this fact, macro variables account for 64 percent, and long-term debt quantities account for 14 percent of the variation in the long-term yield spreads. Latent demand of European investors accounts for 13 percent, and latent demand of offshore financial centers accounts for 4 percent of the variation in the long-term yield spreads. This finding that only the latent demand of euro area investors matters is consistent with currency bias in sovereign debt portfolios (Maggiori, Neiman, and Schreger 2018).

Figure 5 shows the time series of the annual change in the long-term yield spread between southern euro countries and Germany and their decomposition into changes due to macro variables, long-term debt quantities, and latent demand. The most influential observations are the sharp increase in the long-term yield spread at the onset of the European sovereign debt crisis in 2011, followed by a sharp decrease when the European Central Bank intervened in 2012. Consistent with the variance decomposition in Table 8, the figure shows high correlation between the overall change in the long-term yield spread and the changes due to macro variables, long-term debt quantities, and latent demand. A close examination reveals an interesting difference between Greece versus Italy and Portugal. For Greece, macro variables, which include equity volatility and sovereign debt ratings, account for the sharp increase in the credit spread. For Italy and Portugal, latent demand, which captures perceived rather than realized risk, account for the sharp increase in the credit spread. This finding is consistent with the narrative that Greece had a realized solvency problem, while investors perceived Italy and Portugal to be still solvent but vulnerable.

V. Convenience Yield on US Assets

US assets enjoy a special status in global financial markets because the US dollar is the most important reserve currency (Gourinchas and Rey 2007). The demand system that we have estimated in Section III captures the special status of US assets through fixed effects for US issuance interacted with year. Because these fixed effects are significantly positive, the demand for US assets are much higher than other countries' assets, controlling for observed characteristics. By setting the fixed effects to zero for all asset classes and computing counterfactual prices through market clearing, we infer the convenience yield on US assets. By how much would US asset prices decrease (and expected returns increase) if they were not special?

In the absence of special status, the US dollar would be weaker and expected to appreciate at a higher rate. As reported in Table 9, the expected annual appreciation of the US dollar relative to a value-weighted portfolio of foreign currencies would be 1.28 percentage points higher. The demand system allows us to trace the investor origins of this convenience yield into a sum of 0.06 percent for foreign exchange reserves, 0.04 percent for North American investors, 0.35 percent for European investors, 0.41 percent for Pacific investors, 0.33 percent for offshore financial centers, 0.07 percent for emerging market investors, and 0.03 percent for other countries. For example, the convenience yield on the US dollar would be 0.35 percentage points lower at 0.93 percent instead of 1.28 percent in the absence of special-status demand from European investors.

In the absence of special status, the US long-term yield would be 2.15 percentage points higher, confirming the special status of Treasury debt in global financial markets (Jiang, Krishnamurthy, and Lustig 2018). We trace the investor origins of this convenience yield and find that the most important sources are 0.48 percent for foreign exchange reserves, 0.51 percent for European investors, 0.52 percent for Pacific investors, and 0.53 percent for offshore financial centers. Figure 6 reports the time series of US long-term yield and its convenience yield. The convenience yield tends to be countercylical and increased to 3.15 percent in 2011 during the European sovereign debt crisis.

In the absence of special status, the US annual expected stock return would be 1.70 percentage points higher. We trace the investor origins of this convenience yield and find that the most important sources are 0.21 percent for North American investors, 0.69 percent for European investors, 0.37 percent for Pacific investors, and 0.38 percent for offshore financial centers.

VI. Conclusion

Based on a demand system approach, we have developed an international asset pricing model to study sources of variation in exchange rates and asset prices. We conclude with three broad lessons. First, the significance of substitution effects across asset classes highlights the need to study exchange rates, long-term yields, and stock prices jointly. Second, central banks play an important role in managing exchange rates and the term structure of interest rates globally. Short-term rates account for 8 percent of the variation in exchange rates and 9 percent of the variation in long-term yields. Long-term debt quantities account for 20 percent of the variation in long-term yields. Foreign exchange reserves account for 19 percent of the variation in exchange rates and 11 percent of the variation in long-term yields. Third, the convenience yield on US assets is large across all asset classes, and the importance of special-status demand is geographically dispersed.

Based on a vector autoregression, Clarida and Gali (1994), Eichenbaum and Evans (1995), and Inoue and Rossi (2018) 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. The demand system approach models this mechanism directly, based on market clearing of global financial markets. Therefore, it is suited for studying the simultaneous and cumulative impact of conventional and unconventional monetary policy across many countries. An important avenue of future work is to apply a demand system approach to better understand event study estimates of the impact of monetary shocks on asset prices (Koijen et al. 2018).

In the spirit of portfolio balance models in international finance, we have focused entirely on financial markets in this paper. Future work could extend our framework to the real side of the economy. Recent work on international macro models emphasizes the need for latent demand (i.e., demand shocks unrelated to fundamentals) to resolve longstanding puzzles in international finance (Blanchard, Giavazzi, and Sa 2005; Gabaix and Maggiori 2015; Itskhoki and Mukhin 2017). A critique of this literature is that latent demand is an unmeasurable "wedge" without a structural interpretation. The demand system approach shows otherwise, that latent demand could be estimated from international holdings data. Therefore, the variance decompositions in this paper are useful for isolating important sources of variation to estimate and test existing international macro models and to help design future models.

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Table 1
Market values of Financial Assets

Country	Short-term debt: Billion US$	Short-term debt: Share in reserves	Long-term debt: Billion US$	Long-term debt: Share in reserves	Equity: Billion US$	Equity: Share in reserves
Developed markets: North America						
Canada	168.7	0.09	859	0.13	2,367	0.00
United States	822.7	0.34	7,402	0.28	32,121	0.01
Developed markets: Europe						
Austria			308	0.15	151	0.00
Belgium			364	0.12	438	0.00
Finland			183	0.13	204	0.01
France			1,928	0.17	2,749	0.01
Germany			1,740	0.31	2,262	0.01
Italy			1,042	0.07	735	0.00
Netherlands			1,398	0.08	1,100	0.01
Portugal			106	0.05	76	0.00
Spain			762	0.08	889	0.00
Euro	892.3	0.26				
Denmark	19.0	0.35	214	0.07	592	0.00
Israel	0.6	0.00	29	0.01	231	0.00
Norway	18.5	0.11	222	0.07	287	0.00
Sweden	99.3	0.12	386	0.07	699	0.00
Switzerland	33.6	0.19	112	0.03	1,686	0.00
United Kingdom	352.9	0.06	1,948	0.08	3,246	0.01
Developed markets: Pacific						
Australia	95.9	0.09	637	0.14	1,508	0.00
Hong Kong	34.6	0.15	100	0.01	4,351	0.00
Japan	441.4	0.36	474	0.22	6,223	0.00
New Zealand	2.4	0.07	51	0.08	95	0.00
Singapore	63.7	0.24	88	0.06	787	0.00
Emerging markets						
China	101.1	0.17	237	0.25	8,711	0.00
Colombia	0.2	0.00	60	0.01	121	0.00
Czech Republic	15.5	0.00	34	0.02	25	0.00
Greece			26	0.05	51	0.00
Hungary	0.3	0.00	35	0.02	32	0.00
India	10.6	0.00	78	0.01	2,332	0.00
Malaysia	6.8	0.25	63	0.03	456	0.00
Mexico	10.7	0.08	259	0.02	417	0.00
Philippines	1.4	0.00	28	0.10	290	0.00
Poland	0.1	0.00	111	0.07	201	0.00
Russia	0.4	0.00	61	0.00	623	0.00
South Africa	0.2	0.00	63	0.01	1,231	0.00
South Korea	20.1	0.38	137	0.18	1,772	0.00
Thailand	3.4	0.00	28	0.00	549	0.00

The market value of short- or long-term debt is the total amount held by foreign investors. The market value of equity is total stock market capitalization. Short-term debt is aggregated for the ten countries in the table that are in the euro area. All market values are in billion US dollars at year-end 2017.

Table 2
Top Ten Investors by Asset Class

Short-term debt		Long-term debt		Equity	
Investor	Billion US$	Investor	Billion US$	Investor	Billion US$
Reserves	912	Reserves	4,381	United States	32,799
Ireland	527	Japan	2,176	China	8,194
United States	488	United States	2,165	Japan	5,343
Luxembourg	361	Germany	2,002	Hong Kong	4,198
France	215	Luxembourg	1,995	United Kingdom	2,867
Cayman Islands	188	France	1,489	Canada	2,846
United Kingdom	126	Ireland	1,317	France	1,971
Hong Kong	111	United Kingdom	1,038	Luxembourg	1,952
Singapore	84	Netherlands	909	India	1,828
Switzerland	55	Cayman Islands	834	Australia	1,629

The IMF aggregates foreign exchange reserves across all central banks for confidentiality. All market values are in billion US dollars at year-end 2017.

TABLE 3
PREDICTIVE REGRESSION

Variable	Short-term debt	Long-term debt	Equity
Log market-to-book	-7.78	-0.45	-0.29
	(3.49)	(0.13)	(0.22)
Log real exchange rate	-0.31	-0.37	-0.88
	(0.08)	(0.11)	(0.30)
Observations	375	540	540

The estimation is equation (4). For debt, log market-to-book is minus maturity times the continuously compounded yield. All specifications include country fixed effects. Robust standard errors clustered by year are reported in parentheses. The annual sample period is 2002 to 2017.

Table 4
Estimated Demand within Asset Class

Variable	Short-term debt	Long-term debt	Equity
Expected return	31.53	9.31	4.29
	(5.55)	(0.61)	(0.46)
Log GDP	0.96	0.87	0.80
	(0.04)	(0.01)	(0.01)
Log GDP per capita	1.79	1.42	0.44
	(0.15)	(0.04)	(0.03)
Inflation	-0.51	-0.22	-0.02
	(0.09)	(0.02)	(0.01)
Volatility	-3.78	-1.83	-4.83
	(0.47)	(0.23)	(0.27)
Rating	0.11	0.23	0.08
	(0.02)	(0.02)	(0.01)
Export share	0.35	0.29	0.32
	(0.04)	(0.02)	(0.02)
Import share	-0.03	0.09	0.09
	(0.04)	(0.02)	(0.02)
Distance	-0.20	-0.17	-0.11
	(0.02)	(0.00)	(0.00)
Dummy: Own country			7.21
			(0.13)
Observations	17,293	31,252	30,202
R^2	0.25	0.44	0.66

The estimation equation is equation (13). Sovereign debt rating is a continuous measure equal to minus one times the 5-year default probability. All specifications include fixed effects for the investor country, year, and US issuance interacted with year. Heteroskedasticity-robust standard errors are reported in parentheses. The annual sample period is 2002 to 2017.

Table 5
Estimated Demand across Asset Classes

Variable	Symbol	Estimate
Log outside asset weight:		
Short-term debt	λ_1	0.23
		(0.06)
Long-term debt	λ_2	0.24
		(0.08)
Equity	λ_3	0.50
		(0.03)
Dummy:		
Short-term debt	α_1	-2.21
		(0.25)
Long-term debt	α_2	0.52
		(0.27)
Observations		2,339

Equation (14) is the estimation equation. Heteroskedasticity-robust standard errors are reported in parentheses. The annual sample period is 2002 to 2017.

TABLE 6
VARIANCE DECOMPOSITION OF EXCHANGE RATES AND ASSET PRICES

Variable	Exchange rate	Long-term debt	Equity
Macro variables	0.26	0.16	0.57
	(0.07)	(0.09)	(0.08)
Short-term rates	0.08	0.09	0.06
	(0.05)	(0.03)	(0.07)
Debt quantities	0.02	0.20	0.03
	(0.01)	(0.02)	(0.00)
Reserves	0.19	0.11	0.03
	(0.04)	(0.03)	(0.01)
Latent demand	0.45	0.43	0.31
	(0.04)	(0.06)	(0.06)
North America	0.08	0.05	0.06
	(0.02)	(0.01)	(0.04)
Europe	0.08	0.28	0.13
	(0.02)	(0.03)	(0.03)
Pacific	0.03	0.04	0.11
	(0.01)	(0.01)	(0.04)
Offshore financial centers	0.25	0.05	-0.01
	(0.02)	(0.02)	(0.01)
Emerging markets	0.01	0.01	0.03
	(0.00)	(0.00)	(0.03)
Other countries	0.01	0.00	0.00
	(0.00)	(0.00)	(0.01)
Observations	375	540	540

Variance is value-weighted by size of the corresponding asset market. Heteroskedasticity-robust standard errors are reported in parentheses. The annual sample period is 2002 to 2017.

Table 7
Variance Decomposition of Exchange Rates by Latent Demand

Investor	Within asset class: Short-term debt	Long-term debt	Equity	Across asset classes
Total	0.28	0.03	-0.03	0.17
	(0.03)	(0.02)	(0.01)	(0.03)
North America	0.01	0.00	-0.01	0.08
	(0.02)	(0.00)	(0.00)	(0.02)
Europe	-0.02	0.03	-0.01	0.08
	(0.03)	(0.01)	(0.00)	(0.02)
Pacific	0.01	0.01	0.00	0.01
	(0.02)	(0.01)	(0.00)	(0.01)
Offshore financial centers	0.26	-0.02	0.00	0.00
	(0.03)	(0.01)	(0.00)	(0.02)
Emerging markets	0.01	0.01	-0.01	0.00
	(0.00)	(0.01)	(0.01)	(0.00)
Other countries	0.01	0.00	0.00	0.00
	(0.00)	(0.00)	(0.00)	(0.00)

Variance is value-weighted by size of the short-term debt market. Heteroskedasticity-robust standard errors are reported in parentheses. The annual sample period is 2002 to 2017.

Table 8
Variance Decomposition of Long-Term Yield Spreads

Variable	Germany −US	Southern euro − Germany
Macro variables	-0.02	0.64
	(0.24)	(0.13)
Short-term rates	0.53	0.00
	(0.16)	(0.00)
Debt quantities	0.15	0.14
	(0.06)	(0.04)
Reserves	0.20	0.04
	(0.20)	(0.03)
Latent demand	0.14	0.19
	(0.12)	(0.12)
North America	-0.02	0.01
	(0.03)	(0.01)
Europe	0.04	0.13
	(0.07)	(0.08)
Pacific	0.02	0.01
	(0.05)	(0.00)
Offshore financial centers	0.07	0.04
	(0.10)	(0.02)
Emerging markets	0.00	0.00
	(0.01)	(0.00)
Other countries	0.01	-0.01
	(0.01)	(0.01)
Observations	15	45

The southern euro countries are Greece, Italy, and Portugal. Heteroskedasticity-robust standard errors are reported in parentheses. The annual sample period is 2002 to 2017.

Table 9

Average Convenience Yield on US Assets

Investor	Exchange rate	Long-term debt	Equity
Total	1.28	2.15	1.70
	(0.40)	(0.14)	(0.15)
Reserves	0.06	0.48	-0.07
	(0.14)	(0.02)	(0.01)
North America	0.04	0.02	0.21
	(0.00)	(0.00)	(0.02)
Europe	0.35	0.51	0.69
	(0.06)	(0.03)	(0.04)
Pacific	0.41	0.52	0.37
	(0.06)	(0.05)	(0.03)
Offshore financial centers	0.33	0.53	0.38
	(0.15)	(0.05)	(0.05)
Emerging markets	0.07	0.05	0.09
	(0.01)	(0.01)	(0.02)
Other countries	0.03	0.04	0.03
	(0.01)	(0.00)	(0.00)

Convenience yield is reported as an annual percentage. The three columns report expected appreciation of the US dollar relative to a value-weighted portfolio of foreign currencies, US long-term yield, and US expected stock return. Heteroskedasticity-robust standard errors are reported in parentheses. The annual sample period is 2002 to 2017.

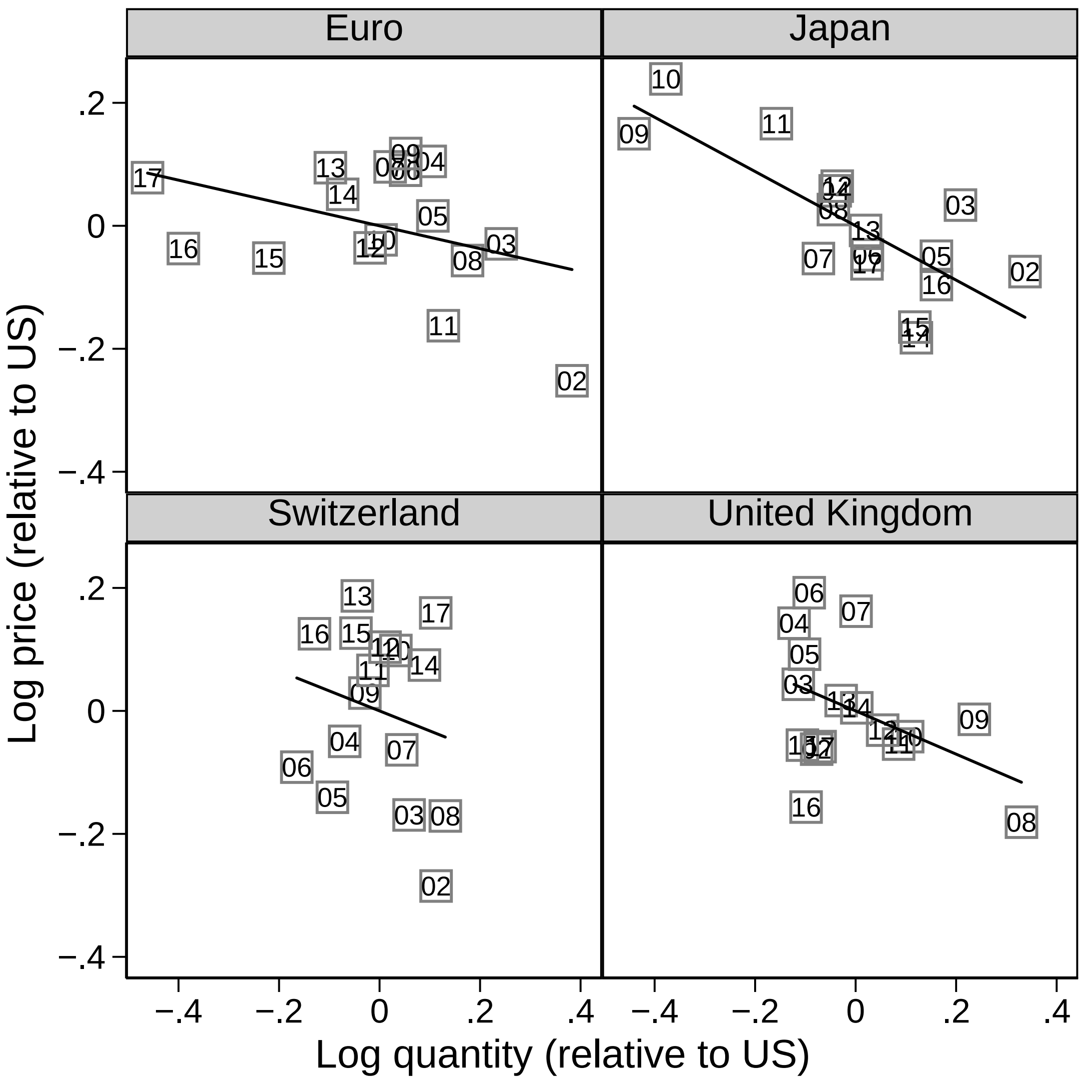

Figure 1. Relative Long-Term Debt Quantity and Price

The horizontal axis is each region's log face amount of long-term debt in local currency unit minus log face amount of US long-term debt (in US dollars). The vertical axis is each region's log long-term bond price plus log exchange rate (in US dollars per local currency unit) minus US log long-term bond price. For the euro area, log price is a weighted average across countries, based on size of the long-term debt market. The two digit number represents year (e.g., 02 is 2002). Each panel reports the linear regression line.

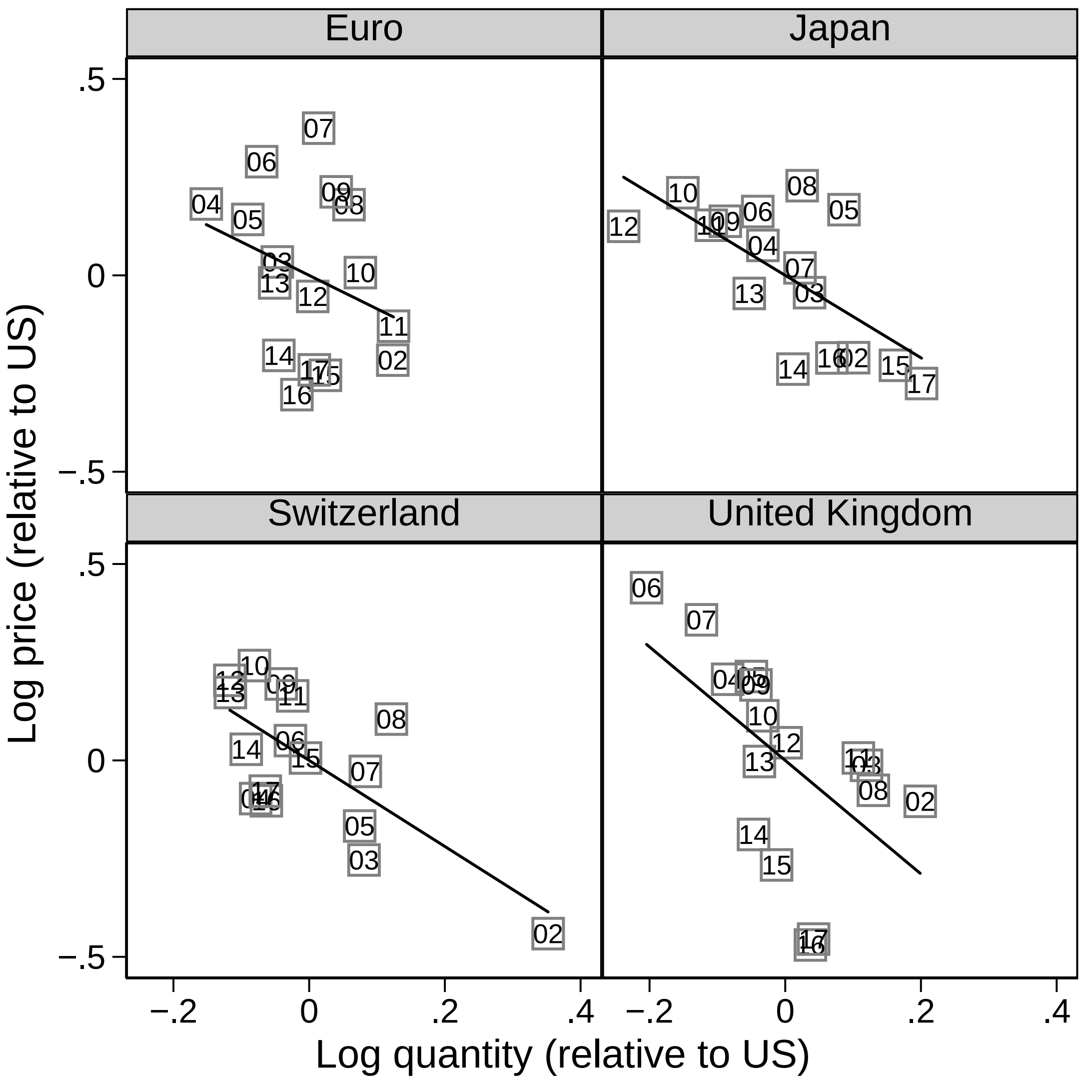

Figure 2. Relative Equity Quantity and Price

The horizontal axis is each region's log book equity in local currency unit minus US log book equity (in US dollars). The vertical axis is each region's log market-to-book equity plus log exchange rate (in US dollars per local currency unit) minus US log market-to-book equity. For the euro area, log price is a weighted average across countries, based on size of the equity market. The two digit number represents year (e.g., 02 is 2002). Each panel reports the linear regression line.

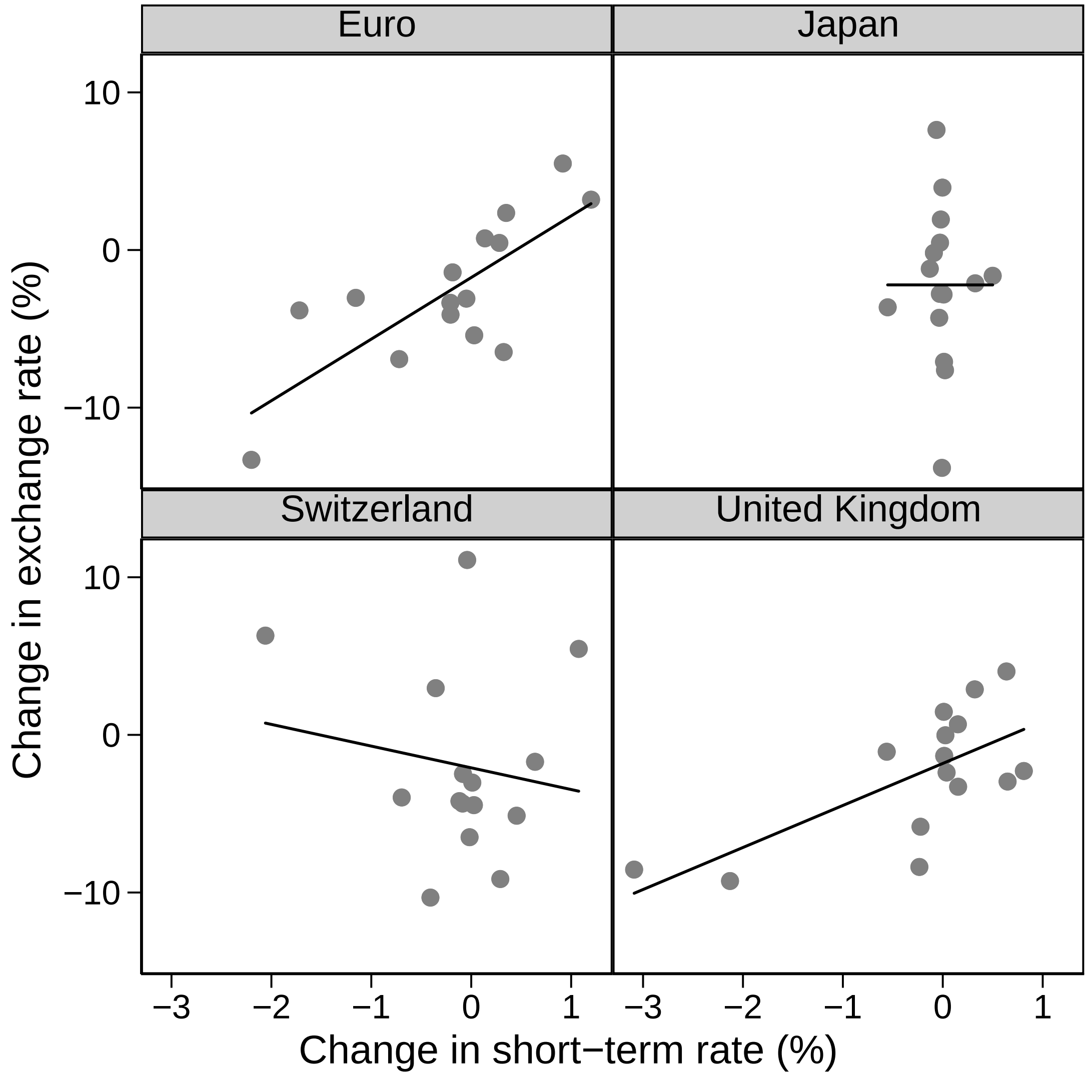

Figure 3. How Exchange Rates Relate to Short-Term Rates

The annual change in the exchange rate is decomposed into macro variables, short-term rates, long-term debt quantities, foreign exchange reserves, and latent demand. This figure reports the changes due to short-term rates only. Each panel reports the linear regression line. The annual sample period is 2002 to 2017.

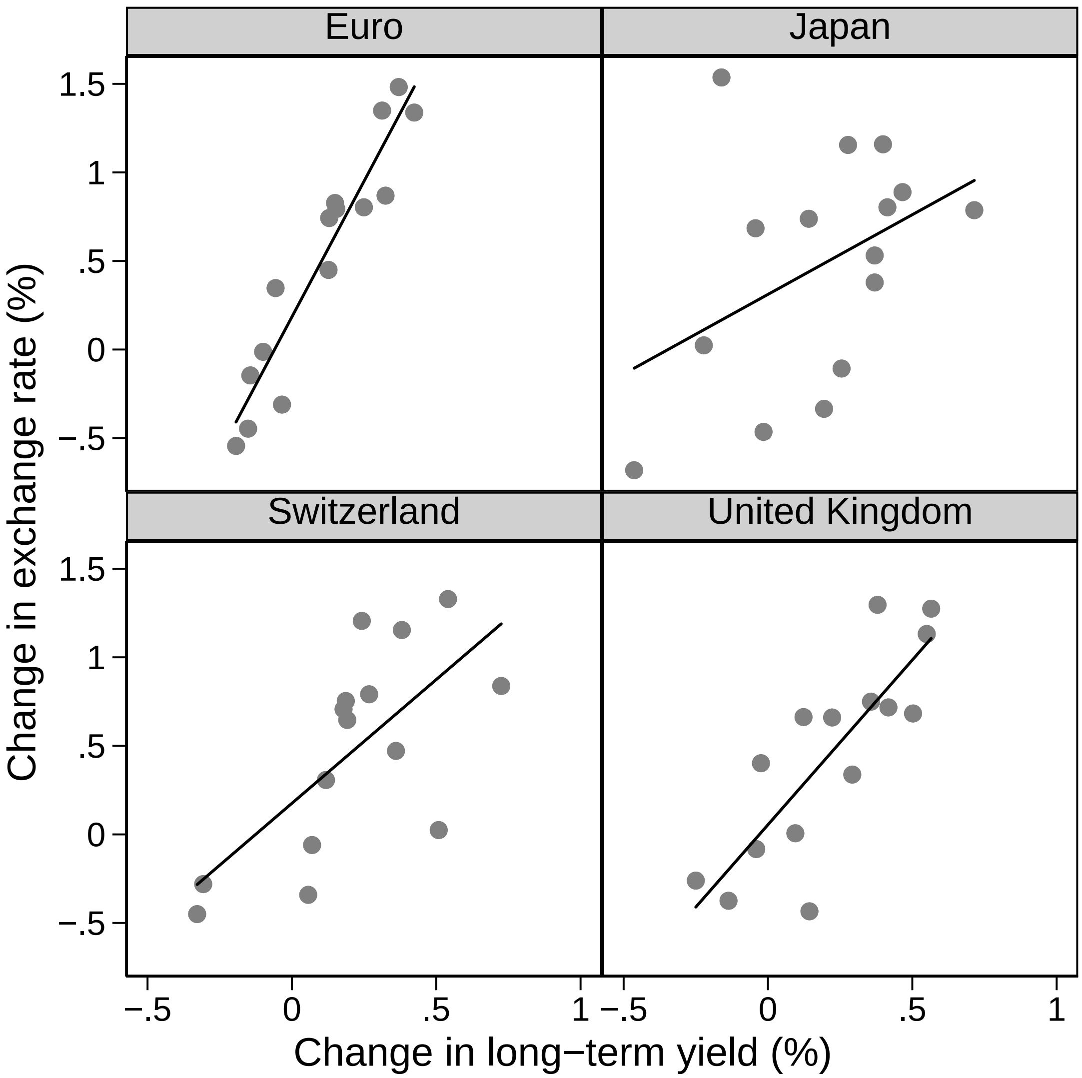

Figure 4. How Long-Term Yields and Exchange Rates Relate to Debt Quantities
The annual changes in the exchange rate and the long-term yield are decomposed into macro variables, short-term rates, long-term debt quantities, foreign exchange reserves, and latent demand. This figure reports the changes due to long-term debt quantities only. For the euro area, the long-term yield is a weighted average across countries, based on size of the long-term debt market. Each panel reports the linear regression line. The annual sample period is 2002 to 2017.

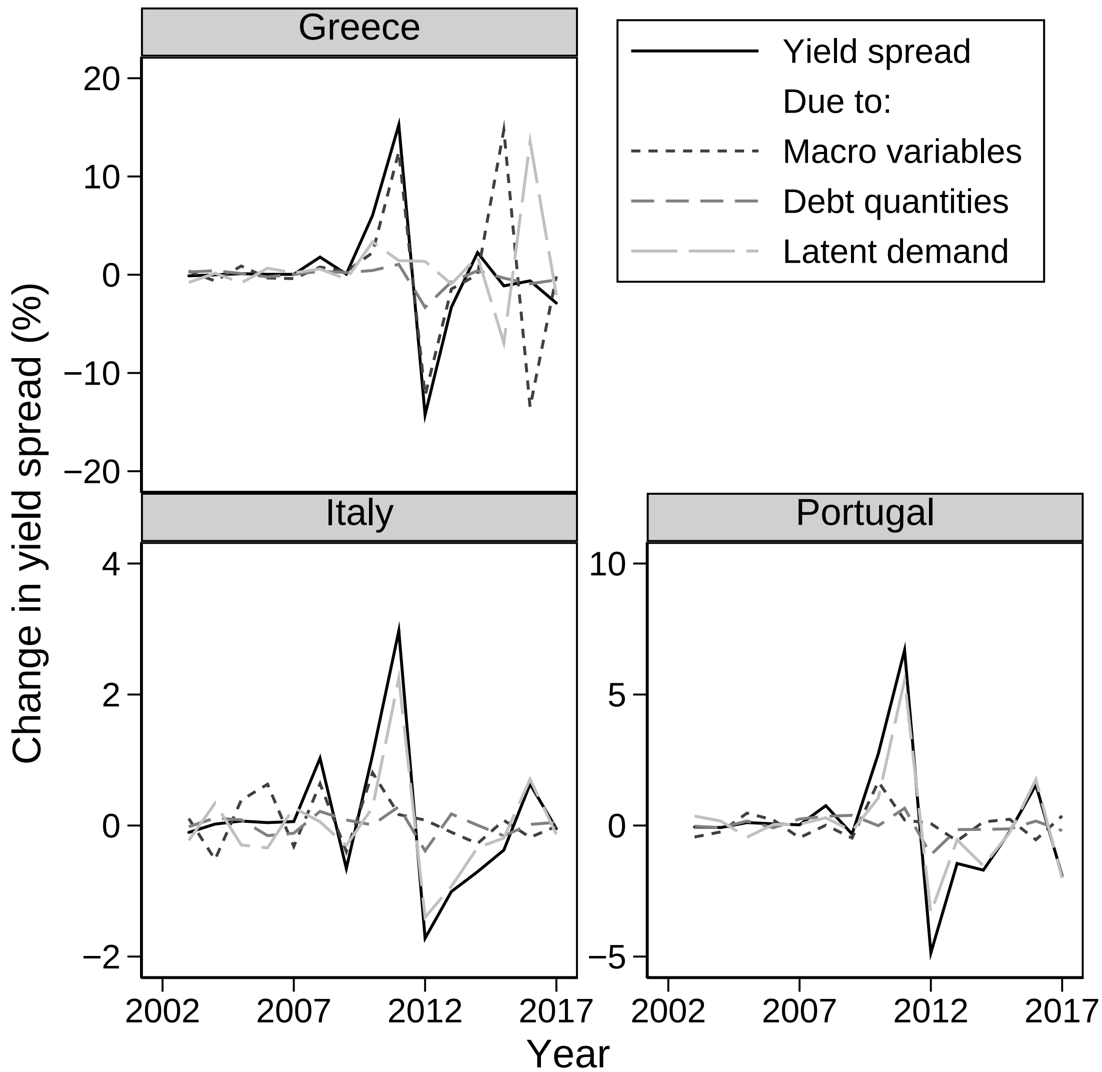

Figure 5. Change in the Long-Term Yield Spread between Southern Euro Countries and Germany

The annual change in the long-term yield spread is decomposed into macro variables, short-term rates, long-term debt quantities, foreign exchange reserves, and latent demand. This figure reports the changes due to macro variables, long-term debt quantities, and latent demand only.

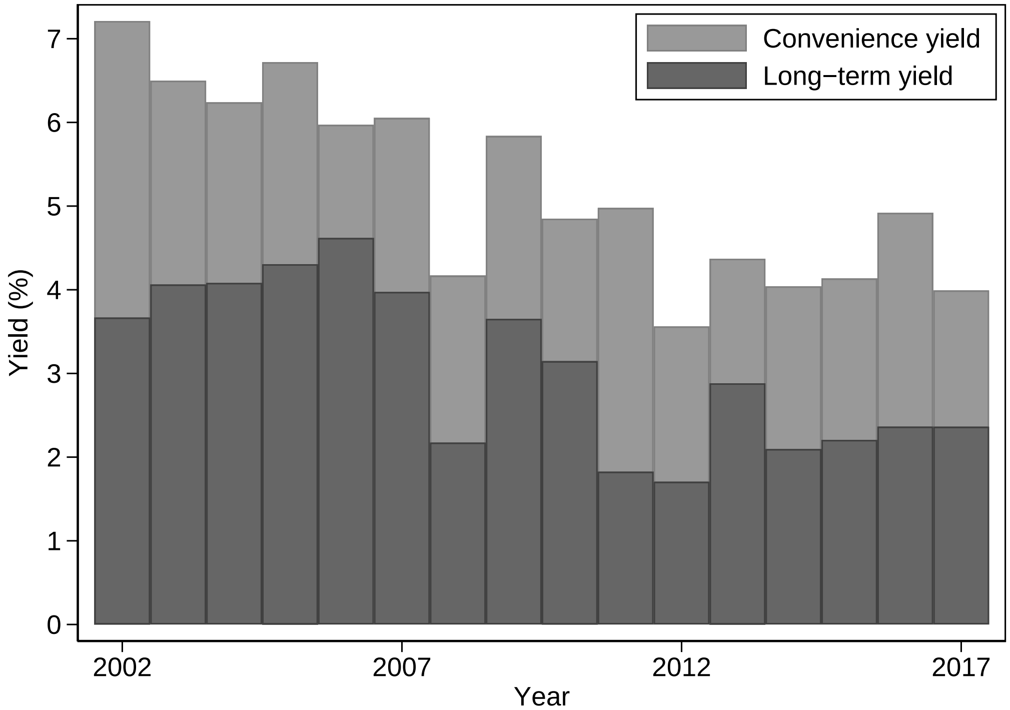

Figure 6. US Long-Term Yield and Its Convenience Yield

The convenience yield is the additional yield on US long-term debt implied by the demand system in the absence of fixed effects for US issuance interacted with year.

For Online Publication

Appendix A. Data Construction

A. International Holdings

Table A1 contains the complete list of 88 investor countries. The 36 countries in bold are also issuer countries, for which we have complete data on asset prices and characteristics. Based on their MSCI classification, we group the countries into developed markets in three regions (North America, Europe, and Pacific) and emerging markets. 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. The "other countries" in Table A1 are neither part of the MSCI ACWI Index nor an offshore financial center.

Mutual funds and investment companies domicile in offshore financial centers because of favorable regulation and taxes. Consequently, offshore financial centers have large amounts of investment from investor countries that pass through to issuer countries. The IMF's Coordinated Portfolio Investment Survey counts these investments twice, once as investment from an investor country and again as investment to an issuer country (International Monetary Fund 2002, p. 72). To eliminate double counting, we do not count investment from an investor country to an offshore financial center. This is equivalent to treating the aggregate holdings of an offshore financial center as an investor unit without breaking them apart by the ultimate investor, which would require some assumptions and imputations.

The IMF does not report confidential holdings. For each investor-issuer pair, we impute the missing observation based on the last (if available) or next observed holding. We assume that the investment amount does not change from one year to the next. If the data are always confidential for an investor-issuer pair, we assume that the investment amount is zero.

The IMF reports small holdings less than \$0.5 million as zero. For these cases, we first distinguish an actual zero from a censored zero based on the panel dimension. If the reported amount has always been zero for an investor-issuer pair, we assume that the investment amount is an actual zero. If the reported amount has been positive in the past, we assume that the investment amount is a censored zero. We estimate a censored regression model of log investment amount onto investor and issuer fixed effects by year and asset class. We impute the censored observation as the predicted value from the regression, conditional on censoring at \$0.5 million.

Long-term debt includes both government and corporate debt. Unfortunately, there is

Table A1
List of Investor and Issuer Countries

Country	Country
Developed markets: North America	*Offshore financial centers*
Canada	Bermuda
United States	Cayman Islands
Developed markets: Europe	Guernsey
Austria	Ireland
Belgium	Isle of Man
Denmark	Jersey
Finland	Luxembourg
France	Netherlands Antilles
Germany	*Other countries*
Israel	Albania
Italy	Argentina
Netherlands	Aruba
Norway	Bahamas
Portugal	Bahrain
Spain	Barbados
Sweden	Belarus
Switzerland	Bolivia
United Kingdom	Bulgaria
Developed markets: Pacific	Costa Rica
Australia	Curacao
Hong Kong	Cyprus
Japan	Estonia
New Zealand	Gibraltar
Singapore	Honduras
Emerging markets	Iceland
Brazil	Kazakhstan
Chile	Kosovo
China	Kuwait
Colombia	Latvia
Czech Republic	Lebanon
Egypt	Lithuania
Greece	Macao
Hungary	Macedonia
India	Malta
Indonesia	Mauritius
Malaysia	Mongolia
Mexico	Panama
Pakistan	Romania
Peru	Saudi Arabia
Philippines	Slovakia
Poland	Slovenia
Russia	Ukraine
South Africa	Uruguay
South Korea	Vanuatu
Thailand	Venezuela
Turkey	West Bank and Gaza

The countries in bold are issuer countries with complete data on asset prices and characteristics.

no tractable way to separate the two for all countries. Moreover, corporate bond yields are unavailable for many of the 36 countries in the sample. Therefore, we simply assume that the benchmark government bond yield is the representative yield of long-term debt in the international holdings data. Another measurement issue is that a small share of debt may be denominated in a foreign currency. Because there is no tractable way to separate the foreign-currency debt, we simply assume that all debt is denominated in local currency.

B. Asset Characteristics

Nominal GDP in US dollars and real GDP per capita, based on purchasing power parity in constant international dollars, are from the World Bank. CPI inflation rates are from the IMF's International Financial Statistics. Exports and imports are from the UN Comtrade Database. We compute the export share for each pair of countries as exports divided by the geometric average of their nominal GDP. We compute the import share for each pair of countries analogously. The physical distance between each pair of countries is from the GeoDist Database (Mayer and Zignago 2011).

For each country and at each year-end, we estimate the standard deviation of monthly stock returns in US dollars over the past 12 months. We annualize equity volatility by multiplying the monthly standard deviation by $\sqrt{12}$. Sovereign debt ratings are from S&P Capital IQ Entity Ratings. We use the long-term debt rating in local currency (if available) or foreign currency. We convert the rating to a continuous measure based on the 5-year default probability (Standard & Poors 2018, Table 16): 0 percent for AAA to AA−, 1.48 percent for A(+/−), 2.02 percent for BBB(+/−), 2.55 percent for BB(+/−), 5.32 percent for B(+/−), and 33.53 percent for CCC+ and below. Our measure is minus one times the 5-year default probability, so that a higher value implies a higher rating.

Appendix B. Relation between Demand System Asset Pricing and the CAPM

We relate the demand system approach to a traditional model of international finance based on the CAPM. We will ignore time t subscripts to simply notation. Investors have heterogeneous beliefs and disagree about expected returns and risk. Let μ_i be the vector of investor i's expected excess returns on all countries and asset classes. Let

$$\Sigma_i = \Omega_i \Omega_i' + \operatorname{diag}(\omega) \tag{B1}$$

be investor i's perceived covariance matrix of excess returns on all countries and asset classes. Excess returns have a one-factor structure, where Ω_i is the vector of factor loadings and diag(ω) is the diagonal matrix of idiosyncratic variances. We denote the elements of μ_i as $\mu_i(n,l)$ for the expected excess return on asset class l in country n. Similarly, we denote the elements of Ω_i as $\Omega_i(n,l)$. For simplicity, we assume that the idiosyncratic variance is constant across investors and within asset class. We denote the idiosyncratic variance of asset class l as $\omega(l)$.

Investor i's expected excess return on asset class l in country n is

$$\mu_i(n,l) = \mu(n,l) + \zeta_i(n,l). \tag{B2}$$

The first term is a common econometric forecast of excess returns, and the second term is an investor-specific deviation from the forecast. Investor i's perceived factor loading for asset class l in country n is

$$-\Omega_i(n,l) = \frac{\omega(l)\Theta_l'}{\kappa_i}\mathbf{x}_i(n) + \theta_i(n,l). \tag{B3}$$

The factor loading depends on a vector $\mathbf{x}_i(n)$ of the asset's own characteristics and an unobserved (to the econometrician) scalar $\theta_i(n,l)$. The division by an investor-specific scalar

$$\kappa_i = \frac{\Omega_i'\mathrm{diag}(\omega)^{-1}\mu_i}{1+\Omega_i'\mathrm{diag}(\omega)^{-1}\Omega_i}. \tag{B4}$$

is without loss of generality because the asset characteristics are also indexed by i.

Investors have a mean-variance objective function, so their optimal portfolio is the mean-variance portfolio (Markowitz 1952):

$$\mathbf{w}_i = \Sigma_i^{-1}\mu_i. \tag{B5}$$

The Woodbury matrix identity implies that the inverse of the covariance matrix (B1) is

$$\Sigma_i^{-1} = \mathrm{diag}(\omega)^{-1}\left(\mathbf{I} - \frac{\Omega_i\Omega_i'\mathrm{diag}(\omega)^{-1}}{1+\Omega_i'\mathrm{diag}(\omega)^{-1}\Omega_i}\right). \tag{B6}$$

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

$$\begin{aligned} w_i(n,l) =& \frac{\mu_i(n,l) - \kappa_i\Omega_i(n,l)}{\omega(l)} \\ =& \frac{\mu(n,l)}{\omega(l)} + \Theta_l'\mathbf{x}_i(n) + \underbrace{\frac{\zeta_i(n,l) + \kappa_i\theta_i(n,l)}{\omega(l)}}_{\epsilon_i(n,l)}. \end{aligned} \tag{B7}$$

Equation (B7) implies higher portfolio weights on assets with higher expected returns (the first term) and lower risk (the second term). Investors have different portfolios because they have heterogeneous beliefs about expected returns and risk (the second and third terms). Demand system asset pricing amounts to estimating equation (B7) on portfolio holdings data. The actual specification that we estimate in equation (13) is log-linear in expected returns and asset characteristics while equation (B7) is linear. We refer to Koijen and Yogo (2019) for technical details about how more general assumptions imply the logit functional form.

If investors have homogeneous and rational expectations about returns, they have identical portfolios. Then equation (B5) and market clearing (3) imply the CAPM:

$$\mu(n, l) = \sigma^2 \Omega(n, l), \tag{B8}$$

where σ^2 is the variance of the market portfolio return. That is, expected excess returns are linear in factor loadings. In a traditional model of international finance, the consumption goods market determines the exchange rate, and the CAPM determines all asset prices.

Appendix C. Supplemental Tables and Figures

Table C1
Regressions of Changes in Exchange Rates and Asset Prices

Variable	Exchange rate	Long-term debt	Equity
Log GDP	0.73	-0.01	-0.11
	(0.05)	(0.03)	(0.04)
Log GDP per capita	-0.21	-0.08	0.02
	(0.07)	(0.06)	(0.06)
Inflation	0.02	0.17	0.14
	(0.05)	(0.06)	(0.07)
Volatility	-0.16	-0.05	-0.65
	(0.05)	(0.05)	(0.05)
Rating	0.03	-0.22	0.02
	(0.05)	(0.08)	(0.03)
Export share	0.28	0.15	0.03
	(0.13)	(0.11)	(0.12)
Import share	-0.38	-0.18	-0.23
	(0.14)	(0.12)	(0.12)
Relative CPI	0.07	0.05	0.13
	(0.06)	(0.05)	(0.05)
Asset quantity	-0.21	0.53	0.03
	(0.05)	(0.06)	(0.05)
Observations	509	539	539
R^2	0.44	0.46	0.55

Observations are value-weighted by size of the corresponding asset market. All regressors are in first differences. Sovereign debt rating is a continuous measure equal to minus one times the 5-year default probability. Asset quantity is the face value of debt or the book value of equity in local currency unit. All coefficients are standardized. Heteroskedasticity-robust standard errors are reported in parentheses. The annual sample period is 2002 to 2017.

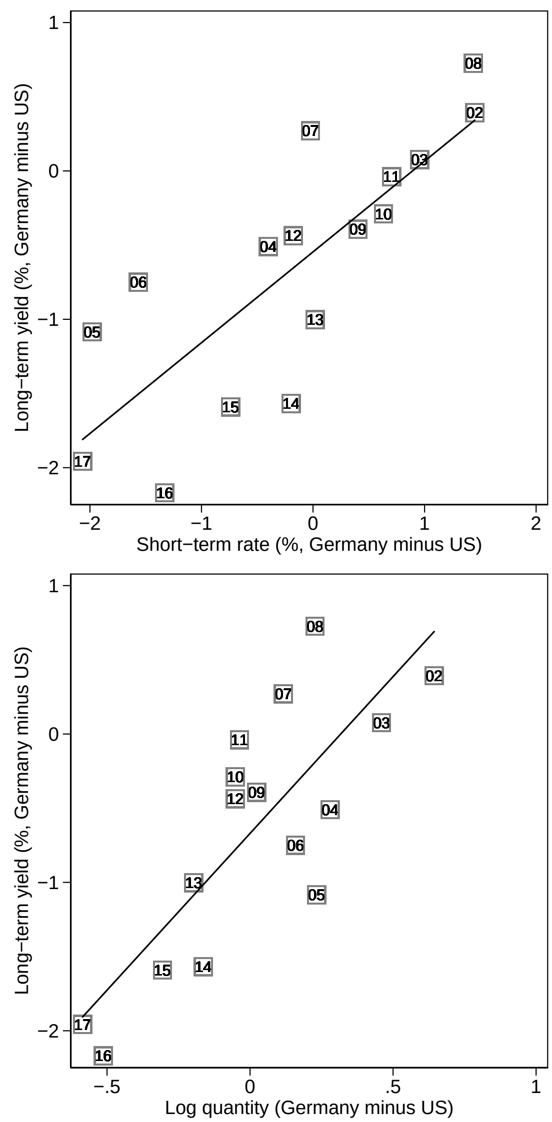

Figure C1. Long-Term Yield Spread between Germany and the US

In the lower panel, the horizontal axis is the German log long-term debt quantity in euros minus US log long-term debt quantity (in US dollars). The two digit number represents year (e.g., 02 is 2002). Each panel reports the linear regression line.