Liquidity and Exchange Rates:

An Empirical Investigation

Charles Engel
Steve Pak Yeung Wu

University of Wisconsin

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Abstract

We find strong empirical evidence that economic fundamentals can well account for nominal exchange rate movements. The important innovation is that we include the liquidity yield on government bonds as an explanatory variable. We find impressive evidence that changes in the liquidity yield are significant in explaining exchange rate changes for all of the G10 countries. Moreover, after controlling for liquidity yields, traditional determinants of exchange rates – adjustment toward purchasing power parity and monetary shocks – are also found to be economically and statistically significant. We show how these relationships arise out of a canonical two-country New Keynesian model with liquidity returns. Additionally, we find a role for sovereign default risk and currency swap market frictions.

Keywords: convenience yield, liquidity, exchange rates disconnect, Meese-Rogoff puzzle
JEL codes: F31, F41

Corresponding Author: Engel. cengel@ssc.wisc.edu. Department of Economics, 1180 Observatory Drive, University of Wisconsin, Madison, WI 53706. We would like to thank many scholars for useful comments, especially Luca Dedola, Harris Dellas, Pierre-Olivier Gourinchas, Zehao Li, Dmitry Mukhin, Maury Obstfeld, Alessandro Rebucci, Andy Rose, and Hyun Song Shin. We thank Yucheng Yang for help in obtaining some of the data.

1. Introduction

The economics literature on foreign exchange rate determination has not had much success linking exchange-rate movements to standard macroeconomic variables. This problem has come to be known at the "exchange-rate disconnect" puzzle, as coined by Obstfeld and Rogoff (2000).[1]

Our tack is to look for the role of the liquidity return on government bonds in driving exchange rates. Engel (2016) suggests that this return – the non-monetary return that government short-term bonds provide because of their safety, the ease with which they can be sold, and their value as collateral, which is sometimes referred to as the "convenience yield" – may be important in understanding exchange rate puzzles.[2]

Our study uses measures of the liquidity yield on government bonds, as constructed by Du, et al. (2018a). These measures take the difference between a riskless market rate and the government bond rate to quantify the implicit liquidity yield on the government bond. Moreover, the Du, et al. measure "corrects" for frictions in foreign exchange forward markets and for sovereign default risk.

The liquidity yield can be associated with the deviation from uncovered interest parity that is now introduced as a standard feature in open-economy New Keynesian models. It is usually included so that the model can reproduce to some extent the observed volatility of real exchange rates.[3] Indeed, Itskhoki and Mukhin (2017) show that this deviation is key to being able to account for the disconnect puzzle. These models inevitably treat the deviation as an unobserved variable. One interpretation of our model and findings is that the uncovered interest parity deviation is partly observable and can be well-measured by the relative liquidity yield on government bonds.

The intuition for why the government bond convenience yield influences the exchange rate is straightforward. The liquidity that these bonds provide is attractive to investors, and influences their investment decisions as if the bonds were paying an unobserved convenience dividend. The government bonds can pay a lower monetary return than other bonds with similar risk

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[1] Engel (2014) provides a recent survey. Itskhoki and Mukhin (2017) is a recent attempt to build a model to account for the disconnect. One notable determinant of nominal exchange rate movements is the lagged real exchange rate, which arises from adjustment to real exchange rate disequilibrium. This point was made clearly by Mark (1995), and has found strong recent support by Eichenbaum, et al. (2018).

[2] Krishnamurthy and Vissing-Jorgensen (2012) and Nagel (2016) study the convenience yield on U.S. Treasury assets. Valchev (2017) also studies a model in which the convenience yield plays a role in accounting for exchange-rate puzzles. del Negro et al. (2018) find that convenience yields account for the long-run drop in global real interest rates.

[3] See Kollmann (2002) for an early example.

characteristics, and still be desirable. An increase in the liquidity yield, as measured by the difference between the private bond return and government bond return, will ceteris paribus lead to a currency appreciation much in the same way that an increase in the interest rate would affect the currency value. However, we note that in our equilibrium model, the liquidity return and the interest rate play somewhat different roles arising from the fact that the monetary policy instrument is the interest rate ex-convenience yield. Thus, the interest rate responds endogenously to inflation in a way that the convenience yield does not.

We find for each of the so-called G10 currencies that the relative liquidity yield (the home country yield relative to foreign country yields) has significant explanatory power for exchange rate movements.[4] That is, the role of the liquidity yield in driving exchange rates is not limited to the U.S., but is evident across all of the major currencies. Moreover, using guidance from a standard New Keynesian model but augmented with a role for liquidity returns on government bonds, we find that the "standard" determinants of exchange rate movements are statistically and quantitatively important after controlling for the liquidity yields. In particular, interest rate differentials and a lagged adjustment term for the real exchange rate (as in Eichenbaum, et al. (2018)) are also important determinants of exchange rate movements. We subject our results to a large number of robustness tests, but find the models perform consistently well. Additionally, we undertake an instrumental variables specification to control for possible endogeneity of the relative liquidity yields, and again find consistently strong support for the model. In an exercise in the spirit of Meese and Rogoff (1983), we find our empirical model has a significantly better out-of-sample fit than a random walk model.

Our study is contemporaneous with Jiang, et al. (2018), but with the following differences: Our empirical work finds strong evidence for the role of government liquidity yields, interest rates and adjustment toward purchasing power parity for ten different currencies, while Jiang, et al. look only at the U.S. dollar. We do numerous robustness checks, and include an instrumental variables specification. And, using the decomposition of Du, et al. (2018a), we find additional explanatory power arising from default risk and forward market frictions in a way that is compatible with our

[4] Namely, Australian Dollar (AUD), Canadian Dollar (CAD), Euro (EUR), Japanese Yen (JPY), New Zealand Dollar (NZD), Norwegian Krone (NOK), Swedish Krona (SEK), Swiss Franc (CHF), British Pound (GBP) and United States Dollar (USD).

model.[5] This latter is important because the premium on government bonds is influenced not only by the liquidity yield, or "convenience yield", of government bonds, but also by default risk and frictions in forward markets for foreign exchange.[6] Finally, our empirical specification is derived from a simple theoretical general equilibrium model.[7]

We think of the liquidity return or convenience yield as arising from the usefulness of some government securities either as collateral for very short-term loans, or from the ease with which they can be sold for cash. Nickolas (2018) defines liquid assets as: "cash on hand or an asset that can be readily converted to cash. An asset that can readily be converted into cash is similar to cash itself because the asset can be sold with little impact on its value." But there is only a fine distinction between liquidity so defined and "safety" as defined by Gorton (2017): "A safe asset is an asset that is (almost always) valued at face value without expensive and prolonged analysis. By design, there is no benefit to producing (private) information about its value, and this is common knowledge." From these definitions, it is clear that safe assets will be liquid, and liquid assets are safe. The role of safe assets in the global economy has been studies extensively in recent literature. In Caballero et al. (2008), Mendoza et al. (2009), Gourinchas and Rey (2011), Maggiori (2017), and Farhi and Maggiori (2018), safe assets play a key role in accounting for global imbalances. Caballero et al. (2015, 2017) explore the role of a shortage of safe assets and their role in the global financial crisis. Gourinchas and Jeanne (2012) explore the consequences of a shortage of safe assets for the stability of the global financial system.

Liquidity and its role in exchange-rate determination has been explored from a variety of angles. The aforementioned papers of Engel (2016) and Valchev (2017) offer models in which certain assets have a convenience yield arising from their liquidity. Grilli and Roubini (1992) and Engel (1992) are earlier, related works. Brunnermeier et al. (2009), Adrian et al. (2009) and Bruno and Shin (2014) consider a liquidity effect on exchange rates arising from banks' balance sheets. One can identify the notions of liquidity in these studies with "funding" liquidity, as defined in

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[5] A small bit of our preliminary findings were first reported at a conference at the Bank for International Settlements on "International macro, price determination and policy cooperation" in September, 2017. The publicly available slides for that lecture can be found at https://www.bis.org/events/confresearchnetwork1709/programme.htm

[6] In fact, Avdjiev, et al. (2018) document the role of deviations from covered interest parity for the value of the U.S. dollar.

[7] Linnemann and Schabert (2015) also posit a relationship between liquidity returns and exchange rate behavior. Their paper does not provide an empirical test of the relationship between the liquidity return and exchange rates. Their model postulates a negative relationship between the liquidity yield and interest rates, contrary to the model of Nagel (2016), Engel (2016), and this paper, and contrary to the evidence in Nagel (2016) and this paper.

Brunnermeier and Petersen (2009), but other work has looked at the role of "market" liquidity. A prominent recent study is Gabaix and Maggiori (2015) that considers financial constraints that prevent full liquidity to arbitrage international money markets. A related study is Pavlova and Rigobon (2008) which investigates the role of portfolio constraints. Melvin and Taylor (2009), Banti et al. (2012), and Mancini et al. (2013) empirically study of the role of liquidity in foreign exchange markets.

There is a long history of attributing a role to the "safe haven" effect on currency values. Recently, Fatum and Yamamoto (2016), which looks at this phenomenon during the global financial crisis, defines a safe currency as "a currency that increases its relative value against other currencies as market uncertainty increases." The idea of a safe haven effect is an old one – see, for example, Dooley and Isard (1985), Isard and Stekler (1985) or Dornbusch (1986). Here we could argue that one channel for the safe haven effect is through the demand for safe assets. During times of global uncertainty, certain assets such as short-term government securities become more valued for their liquidity. There certainly can be other channels through which the safe haven phenomenon works. Farhi and Gabaix (2015) model safe haven currencies as ones that appreciate during times of global downturns, a concept that has been tested empirically by Ranaldo and Söderlind (2010). Obstfeld and Rogoff (2002) speak of risk more generally, which could encompass both the liquidity channel and the hedging channel.

Section 2, which guides our empirical work, presents an equilibrium New Keynesian model in which government bonds pay a liquidity return. Section 3 presents the results of our empirical investigation. Section 4 concludes.

2. Liquidity and Exchange Rates

Following Krishnamurthy and Vissing-Jorgensen (2012), Engel (2016), Nagel (2016), and Jiang, et al. (2018), we posit that the ex ante excess return on short-term government bonds in one country relative to another is attributable to an unobserved liquidity payoff.

In particular, let i_t be the one-period interest rate in the "home" country government bonds (we present the model in the context of two countries, "home" and "foreign".) i_t^m is the return on a short-term, one-period market instrument. The liquidity premium represents the difference in these two rates: $\gamma_t = i_t^m - i_t$. For now, we assume that there is no default risk on either instrument. The empirical section will adjust the returns for default risk using credit default swap (CDS) data.

Under this formulation, we should observe $\gamma_t > 0$, as long as the government bond is more liquid. Investors are willing to hold the government bond instead of the market instrument, because the government bond is more easily sold on markets, or is more readily accepted as collateral. It may be the case that some agents in the economy have no need for liquidity, in which case their holdings of the government bonds would be zero. In particular, it might be that foreign agents hold no home government bonds because they do not value the liquidity of those assets. But private agents cannot short government bonds – that is, private agents (in either economy) cannot borrow at the rate i_t, because the assets they issue do not have the same liquidity as government bonds.

Analogously, in the foreign country, there is a liquidity yield given by $\gamma_t^* = i_t^{*m} - i_t^*$, where the variables with the * superscript denote the foreign-country equivalents of the home-country variables.

We will assume that there is a deviation from uncovered interest parity for the market instruments, r_t, that is stochastic, exogenous and uncorrelated with the other shocks (monetary and liquidity) in the model. We remain agnostic about the source of this deviation. r_t could be a foreign exchange risk premium, a deviation from rational expectations, or some other market friction. In Jeanne and Rose (2002), Devereux and Engel (2002), and Itskhoki and Mukhin (2017), this term arises because of the presence of noise traders. We assume that r_t is uncorrelated with other shocks introduced into the model, to the monetary policy rule and to the liquidity return.[8]

(1) $$i_t^{*m} + E_t s_{t+1} - s_t - i_t^m = r_t,$$

where s_t is the log of the exchange rate (expressed as the home currency price of the foreign currency.)

Let η_t be defined as the liquidity return on home government bonds relative to foreign government bonds:

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[8] Because we do not actually give a structural interpretation to the coefficient estimates of the predictive equation we derive, (18), we can assume something weaker than that the noise term is strictly uncorrelated with the other shocks.

(2) $$\eta_t = \gamma_t - \gamma_t^* = \left(i_t^m - i_t\right) - \left(i_t^{m*} - i_t^*\right) = \left(i_t^m - i_t^{m*}\right) - \left(i_t - i_t^*\right).$$

Then we can rewrite (1) as:

(3) $$i_t^* + E_t s_{t+1} - s_t - i_t = \eta_t + r_t.$$

That is, the expected excess return on foreign one-period government bonds (relative to home bonds) is determined in part by the liquidity yield of home government bonds relative to foreign bonds. When the home bonds are more liquid, the foreign bonds must pay a higher expected monetary return.

Now, iterate equation (3) forward, as in Campbell and Clarida (1987) and others:

(4) $$s_t = -E_t \sum_{j=0}^{\infty} \left(i_{t+j} - i_{t+j}^* - \left(\overline{i - i^*}\right)\right) - E_t \sum_{j=0}^{\infty} \left(\eta_{t+j} - \overline{\eta}\right) - E_t \sum_{j=0}^{\infty} \left(r_{t+j} - \overline{r}\right) + \lim_{k\to\infty} \left(E_t s_{t+k} - k\left(\overline{s_{+1} - s}\right)\right).$$

We will assume that the interest differential, $i_t - i_t^*$; the liquidity return, η_t;, and the u.i.p. deviation, r_t, are all stationary random variables, but s_t follows a unit root process.[9] The unconditional mean difference in the home and foreign interest rate is denoted $\overline{i - i^*}$, the mean of the relative liquidity return is $\overline{\eta}$, and the mean of the interest parity deviation is $\overline{r}$. Here, $\lim_{k\to\infty} \left(E_t s_{t+k} - k\left(\overline{s_{+1} - s}\right)\right)$, which is a random variable when the exchange rate has a unit root, is the permanent component of the nominal exchange rate – in the sense that Beveridge and Nelson (1981) use that term in their permanent-transitory decomposition. The term $\overline{s_{+1} - s}$ represents the trend in the log of the nominal exchange rate.

There is some consensus that nominal exchange rates among high-income countries contain unit roots. For example, if monetary policy is set by a rule for money supplies, any

[9] Technically, we assume $i_t - i_t^*$, η_t, and r_t are square summable, which insures that the infinite sums converge. Any finite order ARMA process, for example, is square summable.

permanent change in the money supply would lead to a permanent change in the nominal exchange rate. If monetary policy is set by an interest-rate rule such as a Taylor rule, the exchange rate will contain a unit root unless the interest rate rule targets the nominal exchange rate.[10]

Equation (4) already points to the intuition of our empirical specification. It says that when the infinite sum of the expected current and future home interest rates rises relative to the expected infinite sum of current and future foreign interest rate, the home currency appreciates (s_t falls.) That is a well-known channel of influence, which is at work in, for example, the famous Dornbusch (1976) model.

However, this comparative statics exercise is made holding the permanent component of the exchange rate constant. All nominal interest rate changes may not be the same. For example, in a traditional monetarist model of exchange rates, a permanent one-time increase in the monetary growth rate in the home country would immediately raise inflation, and therefore raise the inflation premium incorporated in the nominal interest rate. $i_{t+j} - i^*_{t+j}$ would increase for all time periods, but that also implies an increase in the unconditional mean of the relative interest rates, $\overline{i - i^*}$. In that case, there would be no change in the first term on the right hand side of equation (4): $E_t \sum_{j=0}^{\infty} \left(i_{t+j} - i^*_{t+j} - \left(\overline{i - i^*} \right) \right)$ would be unaffected. However, this change would lead to an increase in the permanent component of the exchange rate. The size of the increase is model-dependent, but a classic result is that an increase in the growth rate of *x* percent leads to an immediate permanent depreciation of greater than *x* percent, which the literature referred to as the "magnification effect".[11] The conclusion is that equation (4) by itself, which represents the international financial market equilibrium condition, is not sufficient to determine the exchange rate. In order to determine the exchange rate, we need a model of the determination of interest rates, and of the permanent component of the nominal exchange rate.[12]

Before proceeding to close the model, we note that a higher relative liquidity return on home government bonds also leads to an appreciation of the domestic currency. In this equation, the liquidity return and the interest rate are just two components of the return on government bonds,

[10] See Benigno and Benigno (2008).
[11] See, for example, Frenkel (1976).
[12] Here we differ from Jiang, et al. (2018), who take nominal interest rates as exogenous and assume the nominal exchange rate is stationary.

and so their impact on the exchange rate is identical. In the model that we now present, the interest rates are the monetary policy instruments, and are endogenously determined.

As a first step, we incorporate the model from Engel (2016), based in turn on Nagel (2016), in which the liquidity return on the home bond is positively related to the interest rate:

$$(5) \qquad \eta_t = \alpha\left(i_t - i_t^*\right) + v_t, \quad \alpha > 0.$$

Appendix A1 derives this equation, extending the analysis of Engel (2016). The positive relationship between the relative liquidity return and the interest differential arises as in Nagel (2016). Specifically, when the monetary authority tightens monetary policy by reducing the supply of money and raising interest rates, liquid assets that can substitute for money become more valued for their liquidity services and so pay a higher liquidity return.

The remainder of the model adopts a New Keynesian framework. First, we assume that nominal prices in each country are sticky in nominal terms. In particular, we posit that there is local-currency pricing, so that each firm, in both countries, sets two prices – one in home currency for sale in the home country, and one in foreign currency for sale in the foreign currency.

We modify the standard Calvo-pricing equation in two ways. First, we assume that nominal prices must be set one period in advance. We make this assumption because, in practice, the response of nominal prices to current period shocks is so small relative to the response of nominal exchange rates, that a model with predetermined prices better represents reality in an open-economy framework. A fraction of firms, θ, are allowed to change their prices optimally each period, but the price they set at time $t-1$ is for the time t period. Let $p_t^{r,H}$ be the price for firms that reset their prices (which is identical for all such firms, because as in the standard New Keynesian framework, they face identical costs and demand functions.)

The remaining firms do not change their price optimally, but we assume that these firms build in an automatic price adjustment. We do not specify the trend term, but impose a particular consistency restriction below. We let τ_t^H be the trend adjustment for home prices in the home country (set at time $t-1$.) The firms that adjust their price optimally take into account any current disequilibrium in prices in planning their price increase, while the other firms simply adjust the price at the trend rate.

We have:

(6) $$p_t^H - p_{t-1}^H = \theta\left(p_t^{r,H} - p_{t-1}^H\right) + (1-\theta)\tau_t^H .$$ [13]

The foreign currency price of home goods is set in a similar way:

$$p_t^{*H} - p_{t-1}^{*H} = \theta\left(p_t^{*r,H} - p_{t-1}^{*H}\right) + (1-\theta)\tau_t^{*H}$$

We now make two simplifying assumptions about the price setting process. The first is that firms, when they reset their price, set prices in such a way that there is no expected pricing to market: $p_t^{*r,H} = p_t^{r,H} - E_{t-1}s_t$. We can justify that assumption on the grounds that it is too costly for firms to calculate reset prices for each market they serve. As in the producer currency pricing model, we assume that firms calculate a single reset price, but then translate that price into the currency of each market they service. The local-currency price then remains unchanged until the next opportunity for price resetting. The second assumption is that, while we are agnostic about the process by which firms set the trend adjustment of their prices, we impose the following consistency requirement: $\tau_t^{*H} = \tau_t^H + E_{t-1}s_t - s_{t-1}$. That is, firms form a forecast of the exchange rate change, and then align their trend adjustments so that they are expected to be consistent, when expressed in a common currency, in the home and foreign market. These assumptions imply:

(7) $$p_t^{*H} - p_{t-1}^{*H} = \theta\left(p_t^{r,H} - E_{t-1}s_t - p_{t-1}^{*H}\right) + (1-\theta)\left(\tau_t^H - \left(E_{t-1}s_t - s_{t-1}\right)\right).$$

Subtracting (7) from (6), we find:

(8) $$E_{t-1}s_t - s_{t-1} + p_t^{*H} - p_{t-1}^{*H} - \left(p_t^H - p_{t-1}^H\right) = \theta\left(p_{t-1}^H - s_{t-1} - p_{t-1}^{*H}\right).$$

[13] See Engel (2019) for a study of the relationship of the price setting behavior in this model compared to the more standard Calvo pricing framework.

The expected change in the pricing to market arises from the adjustments of the fraction θ of firms that reset their prices each period.

An analogous equation can be derived for the prices set by the foreign firm: p_t^{*F} in foreign currency for sale in the foreign country, and p_t^F in home currency for sale in the home country:

$$(9) \qquad E_{t-1}s_t - s_{t-1} + p_t^{*F} - p_{t-1}^{*F} - \left(p_t^F - p_{t-1}^F\right) = \theta\left(p_{t-1}^F - s_{t-1} - p_{t-1}^{*F}\right).$$

We assume that consumption preferences over the two goods are identical so that the real exchange rate is driven entirely by the deviations from the law of one price that arise from pricing to market. The log of the consumer price basket in each country is a weighted average of the logs of the prices of foreign-produced and home-produced goods. Taking the weighted average of equations (8) and (9), we arrive at:

$$(10) \qquad \pi_t - \pi_t^* = \theta q_{t-1} + E_{t-1}s_t - s_{t-1}.$$

In this equation, q_{t-1} is the log of the real exchange rate (the price of the consumer basket in the foreign country relative to the home country), π_t is home consumer price inflation between $t-1$ and *t*, and π_t^* is foreign consumer price inflation. Note that because prices are set one period in advance, the inflation rates, π_t and π_t^*, are observable at time $t-1$. Under this specification of price adjustment, the real exchange rate is a stationary random variable and long-run purchasing power parity holds. The pricing to market disequilibria are expected to dissipate over time.

These small modifications to the standard open-economy Phillips curve are introduced here in order to motivate our empirical model of the exchange rate in an intuitive way. In particular, as is well-known from Benigno (2004), price stickiness would not matter at all for the adjustment of the real exchange rate with a standard Calvo-pricing equation, unless interest-rate smoothing is introduced into the monetary policy rule. Engel (2019) shows how the Phillips curve here, along with serially correlated errors in the monetary policy rule produces very similar real exchange rate behavior as the Calvo pricing model with interest rate smoothing, but this model is more analytically convenient.

The final component of the model is the characterization of monetary policy behavior. We model this as a very simple Taylor rule. In the home country:

(11) $i_t = \sigma \pi_t + u_t$.

We impose the so-called Taylor condition, $\sigma > 1$, which is a stability condition in our model. u_t is a deviation from the monetary policy rule. There is an analogous equation in the foreign country, which targets consumer price inflation in that country. Subtracting the foreign Taylor rule from the home Taylor rule gives us:

(12) $i_t - i_t^* = \sigma\left(\pi_t - \pi_t^*\right) + u_t - u_t^*$.

We assume that the relative error terms in the monetary rules follow a first-order autoregressive process:

(13) $u_t - u_t^* = \delta\left(u_{t-1} - u_{t-1}^*\right) + \xi_t, \quad 0 \le \delta < 1$

where ε_t is a mean-zero, i.i.d. random variable.

Equations (3), (5), (10) and (12) – the international financial market equilibrium condition, the model of the liquidity premium, the (relative home to foreign) open economy Phillips curve, and the (home relative to foreign) monetary policy rule – give us a complete dynamic system for the real exchange rate, inflation and interest rates. The model incorporates slow adjustment of the real exchange rate because of nominal price stickiness, governed by the parameter θ, the fraction of the firms that reset their price optimally each period. As Eichenbaum, et al. (2018) have recently emphasized, empirically almost all of the adjustment of real exchange rate comes through adjustment by the nominal exchange rate. That is, inflation rates in each currency play little role in the expected convergence of the real exchange rate to its unconditional mean (which is normalized to zero, meaning the deviations from the law of one price are expected to disappear in the long run.) Eichenbaum, et al. (2018) demonstrate that this empirical regularity can be captured in a New Keynesian model with strong inflation targeting (large value of σ). When inflation targeting is strong, inflation has a low variance even if the variance of the real exchange rate is large. If inflation does not move enough to achieve real exchange rate adjustment, that role is left to the nominal exchange rate.

The sources of shocks in this simplified model are monetary shocks (in equation (12)), the uncovered interest parity shocks in equation (1), and liquidity shocks in equation (5). We have already noted that monetary shocks are assumed to be follow an AR(1) process. We assume that there is persistence in liquidity, and that v_t also follows a first-order autoregressive process:

$$(14) \qquad v_t = \rho v_{t-1} + \varepsilon_t,$$

where ε_t is mean-zero, i.i.d., and $0 \le \rho < 1$. Furthermore, we assume that the deviation from uncovered interest parity also follows an autoregressive process given by:

$$(15) \qquad r_t = \varsigma r_{t-1} + \omega_t, \qquad 0 \le \varsigma < 1.$$

The model can be solved by hand. For the real exchange rate, we find:

$$(16) \qquad \begin{aligned} q_t = &-\left(\frac{\sigma(1+\alpha)+\theta-1}{\theta}\right)(\pi_t - \pi_t^*) - \left(\frac{(1+\alpha)(\sigma(1+\alpha)+\theta-1)}{\theta(\sigma(1+\alpha)-\delta)}\right)(u_t - u_t^*) \\ &-\left(\frac{\sigma(1+\alpha)+\theta-1}{\theta(\sigma(1+\alpha)-\rho)}\right)v_t - \left(\frac{\sigma(1+\alpha)+\theta-1}{\theta(\sigma(1+\alpha)-\varsigma)}\right)r_t \end{aligned}.$$

The inflation variables at time *t* are predetermined, so (16) expresses the real exchange rate in terms of predetermined and exogenous variables. A relative monetary tightening in the home country (an increase in $u_t - u_t^*$) causes a real appreciation of the home currency. Similarly, an increase in the liquidity yield on home government bonds leads to a real appreciation. Note that as inflation targeting becomes more stringent, so σ is larger, the real exchange rate reacts more to monetary policy shocks if $\delta < 1-\theta$. If $\rho < 1-\theta$, a larger σ increases the response of the real exchange rate to changes in the relative liquidity return. We assume in all following discussion that both of the preceding inequalities are satisfied. Also, the greater price stickiness (smaller θ), the larger the response of the real exchange rate to monetary policy shocks and the relative liquidity returns.

We note that the nominal interest differential is simply a linear combination of the predetermined relative inflation rates and the exogenous errors in the monetary policy rules, as given by equation (12). It is intuitive to replace the monetary errors, using (12), with

$$u_t - u_t^* = i_t - i_t^* - \sigma\left(\pi_t - \pi_t^*\right).$$

Then with some rearranging, we can write the solution for the real exchange rate in terms of relative inflation, the nominal interest rate differential, and the liquidity shock:

$$(17)\quad \begin{aligned} q_t =& \left(\frac{\delta\left(\sigma\left(1+\alpha\right)+\theta-1\right)}{\theta\left(\sigma\left(1+\alpha\right)-\delta\right)}\right)\left(\pi_t - \pi_t^*\right) - \left(\frac{\left(1+\alpha\right)\left(\sigma\left(1+\alpha\right)+\theta-1\right)}{\theta\left(\sigma\left(1+\alpha\right)-\delta\right)}\right)\left(i_t - i_t^*\right) \\ & -\left(\frac{\sigma\left(1+\alpha\right)+\theta-1}{\theta\left(\sigma\left(1+\alpha\right)-\rho\right)}\right)v_t - \left(\frac{\sigma\left(1+\alpha\right)+\theta-1}{\theta\left(\sigma\left(1+\alpha\right)-\varsigma\right)}\right)r_t \end{aligned}.$$

In this equation, tighter monetary policy is represented by higher nominal interest rates, which imply a currency appreciation.

Our empirical analysis aims at explaining movements in the log of the nominal exchange rate, $s_t - s_{t-1}$. With some manipulation, using equations (5), (10), and (17), we derive:

$$(18)\quad s_t - s_{t-1} = \beta_1 q_{t-1} + \beta_2\left(\eta_t - \eta_{t-1}\right) + \beta_3\left(i_t - i_t^* - \left(i_{t-1} - i_{t-1}^*\right)\right) + \beta_4 \eta_{t-1} + \beta_5\left(i_{t-1} - i_{t-1}^*\right) + z_{j,t}$$

where

$$\beta_1 = \frac{\left(\theta+\delta-1\right)\sigma\left(1+\alpha\right)}{\sigma\left(1+\alpha\right)-\delta} < 0\ ,\ \beta_2 = -\left(\frac{\sigma\left(1+\alpha\right)+\theta-1}{\theta\left(\sigma\left(1+\alpha\right)-\rho\right)}\right) < 0\ ,\ \beta_3 = -\left(\frac{\sigma\left(1+\alpha\right)+\theta-1}{\theta\left(\sigma\left(1+\alpha\right)-\delta\right)}\right) < 0$$

$$\beta_4 = \frac{\left(\theta+\delta-1\right)\left(\sigma\left(1+\alpha\right)-1\right)\left(\sigma\left(1+\alpha\right)-\rho\right)+\left(\delta-\rho\right)\left(\sigma\left(1+\alpha\right)+\theta-1\right)}{\theta\left(\sigma\left(1+\alpha\right)-\rho\right)\left(\sigma\left(1+\alpha\right)-\delta\right)},$$

$$\beta_5 = \frac{(\theta+\delta-1)(\sigma(1+\alpha)-1)}{\theta(\sigma(1+\alpha)-\delta)} < 0 \text{, and,}$$

$$z_t = -\left(\frac{\sigma(1+\alpha)-1-\theta}{\theta(\sigma(1+\alpha)-\varsigma)}\right)\omega_t + \frac{(\sigma(1+\alpha)-1)(\theta+\delta-\varsigma)+\theta(1-\varsigma)}{\theta(\sigma(1+\alpha)-\delta)} r_{t-1}$$

Our empirical specification for the depreciation of the exchange rate includes, first, an error correction term as the nominal exchange rate adjusts to disequilibrium in the real exchange rate. Second, the change in the interest differential affects the exchange rate as in standard New Keynesian models. Third, the change in the relative liquidity return on government bonds plays a role in influencing the exchange rate. Lagged levels of the relative interest differentials and liquidity returns capture the dynamic adjustment. Under the parameter restrictions of the model – $\sigma > 1$, $\alpha > 0$, $0 \le \theta < 1$, $0 \le \rho < 1$, and $\rho < 1-\theta$ – ceteris paribus, an increase in q_{t-1}, and increase in $i_t - i_t^* - (i_{t-1} - i_{t-1}^*)$, and an increase in $\eta_t - \eta_{t-1}$ all lead to a decline in $s_t - s_{t-1}$. That is, the home currency appreciates to correct for a real undervaluation, and it appreciates in response to a relative increase in either the home interest rate or the home liquidity return. The error term, z_t, is a function of the dynamics of the deviation from uncovered interest parity, which is assumed not to be observable by the econometrician. It is by construction uncorrelated with the explanatory variables in the regression. The derivation implies that there may be serial correlation in the regression error, but in practice we find very little evidence of that – which is consistent with the model under a particular configuration of parameters.

Before turning to the data, we note a few features of our empirical specification based on (18). As in our model, we follow convention and treat nominal exchange rates as non-stationary random variables. In light of much evidence, from Mark (1995) to more recent empirical evidence in Engel (2016) and Eichenbaum, et al. (2018), the real exchange rate is stationary and the nominal exchange rate adjusts in the direction of restoring purchasing power parity. Relative interest rates and relative liquidity returns are stationary. We allow dynamics by including contemporaneous and lagged values of these variables. Because these variables are serially correlated, we enter them in the specification as in (18) with the first difference in the returns and the lagged level of the returns. This reduces the multicollinearity that would be present if these variables were included in contemporaneous and lagged levels, and gives us the natural interpretation that changes in relative interest rates and changes in relative liquidity yields influence changes in the log of the nominal exchange rate.

It is important to note that β_3 measures the impact of monetary policy shocks, $u_t - u_t^*$, on s_t, while β_2 quantifies the effect of shocks to the relative liquidity yield, v_t, on the log of the exchange rate. To see this, first observe from the relative Taylor rules, (12), that the home relative to foreign interest rate differential depends on relative inflation and the monetary policy shocks. However, from equations (10) and (3), we see that relative inflation, $\pi_t - \pi_t^*$ is predetermined and a function of the lagged interest rate differential and liquidity yield, $i_{t-1} - i_{t-1}^*$ and η_{t-1}.[14] Because these latter two variables are controlled for in (18), the independent effect of $i_t - i_t^*$ arises only from the monetary policy shocks. Equation (5) finds η_t is a function of the interest rate differential as well as the independent shocks to liquidity. Since the regression equation controls for $i_t - i_t^*$, the independent effects of the shocks to liquidity are measured by the coefficient on η_t.

3. Empirical Investigation of Government Bond Liquidity and Exchange Rates

In this section, we present our empirical results. We first describe how we construct the measure of government bond liquidity in 3.1. Subsection 3.2 presents our baseline result that the change in the relative government bond liquidity returns is strongly correlated with exchange rate movements. We show our results are robust to controlling for certain market frictions and we estimate instrumental variable regressions in subsection 3.3. In subsection 3.4, we further confirm that country-specific government bond liquidity matters. Finally, in subsection 3.5, we conduct an out-of-sample fit exercise a la Meese and Rogoff (1983) and find that our model's prediction significantly outperforms a random walk model.

Throughout the section, we denote the foreign variable as X_t^* if the context is not country *j* specific. For example, we use i_t^* for the foreign interest rate on a government bond. Whenever

[14] Relative inflation would also be a function of lagged *r*, but we have already argued that because serial correlation is essentially zero in our regressions, the impact of lagged *r* as a "left out" variable in our regressions is minimal.

needed, we denote the variables of a foreign country *j* as $X^*_{j,t}$, for example, $i^*_{j,t}$ for the interest rate of a government bond for the foreign country *j*.

3.1. Construction of Liquidity Measure

The word "liquidity" appears in different economic contexts with different meanings. Here, it refers to a non-observable non-pecuniary return that investors enjoy when holding the asset. We measure the term $i^m_t - i^{m*}_t$ in equation (1) by using the foreign exchange forward minus spot rate spread, $f_{t,t+1} - s_t$:[15]

(19) $$\eta_t \equiv \left(i^m_t - i_t\right) - \left(i^{m*}_t - i^*_t\right) = f_{t,t+1} - s_t + i^*_t - i_t$$

where $f_{t,t+1}$ is the log of forward rate and s_t is the log of the spot exchange rate, both expressed in home currency price of a foreign currency.

There are two ways to interpret η_t . First, as the term $(i^m_t - i_t) - (i^{m*}_t - i^*_t)$ suggests, it is a relative measure of difference between marketable securities and government bond yield in the home and foreign country. This interpretation comes directly from the model. Second, as described by $f_{t,t+1} - s_t + i^*_t - i_t$, the first three terms can be understood as the payoff of a synthetic home government bond that is constructed by buying the foreign government bond, and eliminating exchange rate risk by entering a forward contract. Since the home government bond and the synthetic home government bond pay equivalent pecuniary returns, the difference between the two gives a measure of the relative difference in liquidity services the home and foreign government bonds provide.

In the case where the U.S. is assumed to be the home country, Du, et al. (2018a) denotes the η_t term here as the U.S. Treasury Premium, $\Phi_{j,n,t}$, which is the *n*-year deviation from covered interest parity between government bond yields in the United States and country *j*. Jiang, et al.

[15] We address the issue of deviation of covered interest parity in subsection 3.3.

(2018) take the U.S. as the home country, and define $-\eta_t$ as a cross-country average over nine large markets relative to the dollar.

We employ the procedure developed by Du, et al. (2018a) to obtain η_t for any pair of home currency *i* and foreign currency *j* (90 pairs in total) for the G-10 currencies. To give a sense of how this liquidity measure behaves, we plot the liquidity measure against the nominal exchange rate of each home currency *i* and foreign currency *j* in Figure 1. For each time period, we take a simple average across foreign currency *j* to improve visual representation. It is interesting to see that there is already a negative relationship between the mean exchange rate and mean liquidity measure, meaning a higher government bond liquidity relative to the rest of the G10 currency country is associated with a strong currency contemporaneously. In Table 1, we report the correlation coefficient between the liquidity measure and interest rate differential for each home currency *i* and foreign currency *j*. The correlation coefficients are positive for each currency *i*. This verifies the positive relationship between the relative liquidity return and the interest differential in (5), and is consistent with the empirical findings of Nagel (2016) for the U.S..

Unless otherwise specified, our study uses end-of-month monthly data from January 1999 to December 2017.[16] We use exchange rates and forward rates from Thomson Reuters Datastream. The consumer price indexes and unemployment rates are from the IMF IFS. The government yield data is obtained from Bloomberg, Datastream and central banks. The LIBOR swap rates are from Bloomberg. The Credit Default Swap data is from Bloomberg and IHS Markit. The gold price, VIX index and unemployment rates are from FRED and the government debt to GDP data is from the BIS credit to the non-financial sector dataset (nominal value). We provide the data source details in Appendix A2 and summary statistics for the variables we used in Appendix A3. Supplementary Appendix A4 reports a large number of robustness checks. We employ panel fixed effect regression in all the reported estimates to make use of cross-country time series information but at the same time allow for time-invariant heterogeneity. To account for the possibility of cross-sectional correlated estimation errors, we report standard errors that allow for non-diagonal covariance of the error terms. We estimate the regression using ordinary least squares (OLS). The error terms estimated from the OLS are then used to construct estimates of the variance-covariance

[16] Whenever needed, we linearly interpolate the quarterly variable to monthly variable. For example, we interpolate the Australia and New Zealand CPI to obtain monthly real exchange rates.

matrix of the error term. Consistent statistical inference (for example, significance) can be conducted using this estimated variance-covariance matrix.

3.2 Baseline Results

To investigate the empirical relationship between government bond liquidity and exchange rates for the G10 countries, we estimate the following panel monthly fixed effect regression from equation (18):

$$(20) \qquad \Delta s_{j,t} = \alpha_j + \beta_1 q_{j,t-1} + \beta_2 \left(\Delta \eta_{j,t}\right) + \beta_3 \left(\Delta i^R_{j,t}\right) + \beta_4 \eta_{j,t-1} + \beta_5 i^R_{j,t-1} + u_{j,t} \,,$$

where $i^R_t = i_t - i^*_t, \Delta X_t = X_t - X_{t-1}$ for any variable *X*.

Table 2A reports the regression coefficient estimates of (20).[17] Each row of the table represents the estimation results that take the country of the currency in the first column as the home country and rest of the nine countries as the foreign countries. When constructing the variables, we use one-year forward rates and one-year government yields.[18] The real exchange rates are constructed using consumer price levels.

First, consistent with our theoretical prediction and the empirical results of Eichenbaum, et al (2018), the coefficient estimates for $q_{j,t-1}$ are all negatively significant, implying that real exchange rates adjust through nominal exchange rates. The average coefficient estimate is approximately -0.023, implying a 2.3% adjustment of the nominal exchange rate in the direction of the long-run real exchange rate, per month. It is interesting to note that the estimated adjustment of the dollar exchange rate is around half the size of the average (across currencies) adjustment coefficient, suggesting a more persistent real exchange rate.

Second, we find that a positive change in the relative interest rate (home minus foreign) drives a contemporaneous home currency appreciation, which matches the traditional interest rate and exchange rate relationship. While almost all monetary, sticky-price models of exchange rates predict such a relationship, empirical support for even a contemporaneous relationship between

[17] To keep the table visibly clear, we only report the main coefficient estimates of interest and refer readers to the supplementary appendix for the full regression tables.
[18] See the discussion and robustness below for the choice of one-year tenor.

interest rates and exchange rates has not been universally strong in previous studies.[19] It may be that the importance of the interest rate channel requires controlling for the error-correction term and liquidity yields, as in our specification. We find the interest rate effect is strongly statistically significant for all ten currencies. The average coefficients, across the currencies, is -5.07, which means that a 100 basis point increase in the annualized interest rate in the home currency relative to the foreign country leads on average to a 5.07 percent appreciation from the previous month.

Our main novel results concern the effects of the liquidity yield on exchange rates. The coefficient estimates for $\Delta\eta_{j,t}$ are all negative and statistically significant at the 1% level, with a range from -2.32 to -6.64. This indicates a 2.32% to 6.64% home currency appreciation in a month when there is a positive change of 100 basis points (annualized rate) in relative liquidity. The statistical significance and economic significance of these coefficient estimates are striking given the well-known exchange rate disconnect puzzle. We find that the relative government bond liquidity exhibits a very strong relationship with exchange rate movements for all the G-10 countries.

Table 2A points to two important aspects of the impact of the liquidity yield. First, it is not just a U.S. dollar phenomenon. While a great deal of attention has been paid to the convenience yield on U.S. government bonds, our regression results show that the relative liquidity yield is an important factor in explaining exchange rate changes for all of the G10 currencies. Further results reported in section 3.4 emphasize this point.

However, secondly, the U.S. is still a special case in the sense that the impact of the relative convenience yields on the exchange rate is largest in the U.S. The estimated coefficient on the liquidity yield is largest in absolute value for the U.S., and the size of that impact is substantially larger than for all currencies excepting the Australian dollar and New Zealand dollar.

Omitting the liquidity return

For comparison, we also conduct the regression (20) but excluding the liquidity yield variables. That is:

(21) $$\Delta s_{j,t} = \alpha_j + \beta_1 q_{j,t-1} + \beta_2(\Delta i^R_{j,t}) + \beta_3(i^R_{j,t-1}) + u_{j,t}\,,$$

[19] See Engel (2014) for a recent survey.

The regression estimates are reported in Table 2B. The coefficient estimates on lagged real exchange rates and change in interest rate differential remain negatively significant for all country pairs. However, the within R-squared for this specification are universally much lower compared to Table 2A.[20] This indicates including relative government bond liquidity returns brings strong explanatory power to exchange rate determination, in addition to and independent of the traditional factors.

The statistical significance of the effect of $\Delta\eta_{j,t}$ in our baseline regression, as well as the large drop in R-squared values when this variable is omitted, points to the fact that there is variation in $\Delta\eta_{j,t}$ that is independent of variation in $\Delta i^R_{j,t}$, and important in explaining exchange rate changes. Appendix A.3 shows that while the standard deviation of $\eta_{j,t}$ is small relative to the standard deviation of $i^R_{j,t}$ (on average across the ten currencies, the relative liquidity yields have standard deviations less than 20 percent of the relative interest rates), that is much less true for $\Delta\eta_{j,t}$ and $\Delta i^R_{j,t}$. The average over the currencies of the standard deviation of $\Delta\eta_{j,t}$ is about 80 percent of the standard deviation of $\Delta i^R_{j,t}$. It might be tempting to simply add together the liquidity yield and the interest payments as two components of the return on investments in a country, but our results show that would be a mistaken approach because those two different returns are not highly correlated and have separate effects on exchange rates.

Estimation on sub-samples

Next, we investigate whether the relationship between government bond liquidity and exchange rates are driven by the Global Financial Crisis or the post-crisis period. In Table 2C, we re-estimate (20) but split the sample period into two periods, pre-2008 and post (and including)-2008. We see that the contemporaneous relationship between the change of the liquidity measure and the change of exchange rates holds in both time periods. As in the full sample, all of the estimated coefficients on the impact of the estimated government liquidity return are negative. They are all individually statistically significant at the one percent level in the post-crisis period.

[20] The average R-squared in the baseline regression is 0.150, but only 0.081 in the regressions that omit the liquidity yield.

In the pre-crisis data, the p-values for these coefficients are all less than 0.01 except for Japan and Switzerland but both of them are still with a negative coefficient. The coefficient estimates in all cases have larger values in absolute terms after 2008, ranging from -2.86 to -7.11. In addition to the significant and larger coefficients, the post-2008 R^2 are markedly improved, with a maximum of 33%, reflecting the importance of the relationship between the government bond liquidity and exchange rate determination.[21]

This set of results provides evidence that government bond liquidity at the individual country level plays an important role in exchange rate determination. This contrasts to the belief that there is a special role of the USD or the U.S. Treasury bond. We find that individual country government bond liquidity other than the U.S. is also important in understanding exchange rate fluctuations.

One-month forward rates

As we have noted, in our baseline regressions we use one-year forward rates and one-year government yields as regressors, while the regressions are conducted in monthly frequency. The choice of one-year tenor is a tradeoff between model consistency and data availability. Ideally, for model consistency, we would use one-month forward rates and government yields to construct the variables. However, the data availability of one-month government yields is rather limited for some of the sample countries. In addition, in section 3.3, we use credit default swap (CDS) data to make an adjustment for the probability of non-repayment of government debt. The CDS data is more extensively available only for tenors of one year or above. Therefore, we use one-year forward rates and one-year government yields to construct the variables in our analysis. To be fully consistent with the model, investors would need to have no uncertainty about the one-month own-currency return on one-year bonds, but the variation in that return (annualized) relative to the one-year interest rate is very small relative to changes in exchange rate. The monthly correlation of one-year and one-month interest rates is over 0.90 in our sample for all countries.

Nevertheless, to make sure our result is robust to the choice of tenor, we report in Table 2D the regression coefficient estimates of equation (20), using one-month forward rates and one-

[21] In an country by country estimation of (20) reported in the Supplementary Appendix, the maximum R^2 is 49%, which is the AUD – JPY pair.

month government yield data.[22] The empirical relationship between the change of nominal exchange rate and the independent variables are largely consistent with the result we discussed in Table 2A, which use one-year forward rates and one-year government yields data. In light of this, to make our empirical results comparable across different specifications, we use one-year forward rates and one-year government yields throughout the analysis.

3.3 Decomposing the Liquidity Measure

Up to this point, we have maintained the assumption that markets are frictionless, so we have $\eta_t = f_{t,t+1} - s_t + i_t^* - i_t$ to serve as a measure of relative government bond liquidity. In this subsection, we discuss some frictions that could possibly drive the movement of η_t other than the liquidity of government bonds. As we have noted, η_t can be interpreted as the difference of a synthetic home government bond $f_{t,t+1} - s_t + i_t^*$ and a home government bond i_t . There are two possible frictions to consider – sovereign default risk and a currency derivative market friction. These frictions are important in the recent literature in international finance, and there are readily available prices that can be used to quantify these frictions.[23]

First, investors might not be able to construct the synthetic home government bond as we have posited because of some distortions in currency derivative markets. If covered interest parity held for market returns, we should find $f_{t,t+1} - s_t + IRS_t^* = IRS_t$, where IRS_t (IRS_t^*) refers to the home (foreign) return on LIBOR swaps. Baba et al. (2008), Baba and Packer (2009), and Griffoli and Ranaldo (2011) attribute the failure of covered interest arbitrage in the years immediately following the global financial crisis to both a liquidity and a default factor. In particular, there appeared to be profitable arbitrage opportunities that involved borrowing in dollars and making covered investments in foreign interest-earning assets. These papers provide evidence that investors were reluctant to take advantage of such opportunities both because of counterparty risk, and because there was a global demand for liquid dollar assets. Du, et al. (2018b) find that in recent

[22] Norway is excluded in this exercise as a home country and foreign country due to lack of Norway one-month government yield data.

[23] See Della Corte, et al. (2018) for the effects of sovereign default on exchange rates. Du, et al. (2018b) investigate deviations from covered interest parity and Ajdiev, et al. (2018) consider the relationship between the currency swap friction and the exchange rate.

years, for some currencies (particularly, when the U.S. dollar is the home currency), $IRS_t < f_{t,t+1} - s_t + IRS_t^*$, but financial institutions do not undertake the arbitrage that would result in riskless profits. In order to earn those profits, banks would need to go short in dollars, and purchase the foreign currency on the spot market and go long in foreign currency (which they sell forward.) Such an arbitrage investment, while risk free, expands the size of the financial institutions' balance sheets, and may cause them to run afoul of regulatory constraints. Financial institutions that held home assets could sell those and acquire synthetic home assets, but they might be unwilling to do so if they value the home assets for non-pecuniary reasons. Hence, when home assets are especially valued, then $\tau_t \equiv f_{t,t+1} - s_t + IRS_t^* - IRS_t$ will be high, and the home currency will be strong. The same relationship could arise if there were default risk on LIBOR rates, as might have been the case in 2008 during the global financial crisis. When foreign LIBOR is considered risky, τ_t is high, and the home currency is strong. We note that Cerutti, et al. (2019) associate the failure of covered interest parity for the U.S. dollar with periods of a strong dollar. This opens the question of the channel of causality, which we address in the next section.

Furthermore, even if the currency derivative markets are frictionless, the government bond yields might include expected default risk. If the home government bond is regarded as default-free (say, the U.S. Treasury bond), but the foreign government bond is expected to default with some probability (say, the Japanese Government Bond, due to its high debt to GDP ratio), then the difference between the synthetic home government bond and home government bond could be different not just because of the difference in government bond liquidity but also the difference in default premium. We define $l_{j,t}^R$ as the home minus foreign country *j* expected default loss on government bonds, so that the expected relative return on home government bonds is $i_t - i_{j,t}^* - l_{j,t}^R$. To measure the term $l_{j,t}^R$, we make use of the information from the credit default swap (CDS) market. A CDS contract insures the buyer from credit event. In the case of sovereign default, the CDS sellers make payments to the buyers to compensate for the loss in the credit event. Buyers of CDS pay premium to CDS sellers for getting the insurance. Therefore, the CDS premium quote is an appropriate instrument to reflect the market implied expected default loss. We take the home minus foreign difference of CDS premium quotes as the measure for the expected default loss term, i.e. $l_{j,t}^R = CDS_t - CDS_{j,t}^*$.

To adjust for these frictions, as in Du, et al. (2018a), we can write $\eta_{j,t}$ as a sum of three components:

$$(22) \qquad \eta_{j,t} = \tau_{j,t} - l^R_{j,t} + \lambda_{j,t} ,$$

where $\lambda_{j,t}$ is a residual term. In the frictionless scenario above, we will have $\tau_{j,t} = l^R_{j,t} = 0$ so $\eta_{j,t} = \lambda_{j,t}$. That is, $\lambda_{j,t}$ can be understood as the relative government bond liquidity, after adjusting for the currency derivative market friction and credit default risk.

We below summarize the components of $\eta_{j,t}$ introduced in this subsection:[24]

$$(23) \qquad \tau_{j,t} = f_{t,t+1} - s_t + IRS^*_{j,t} - IRS_t \quad , \quad l^R_{j,t} = CDS_t - CDS^*_{j,t} \quad , \quad \lambda_{j,t} = \eta_{j,t} - \tau_{j,t} + l^R_{j,t}$$

In all cases, we use IRS and CDS data with one-year tenor as the CDS data is extensively available only for tenors of one-year or above.

With these decomposed components on hand, we modify the baseline regression by putting each of the components into the equation. Specifically,

$$(24) \qquad \begin{aligned} \Delta s_{j,t} &= \alpha_j + \beta_1 q_{j,t-1} + \beta_2 \Delta\lambda_{j,t} + \beta_3 \Delta\tau_{j,t} + \beta_4 \Delta l^R_{j,t} + \beta_5 \Delta i^R_{j,t} \\ &\quad + \beta_6 \lambda_{j,t-1} + \beta_7 \tau_{j,t-1} + \beta_8 l^R_{j,t-1} + \beta_9 i^R_{j,t-1} + u_{j,t} \end{aligned}$$

As discussed above, we expect to find a negative estimate of β_3, because a larger $\Delta\tau_{j,t}$ indicates an unwillingness to sell home assets to buy the foreign currency, which appreciates the home currency. The estimated β_4 should be positive, since a larger $\Delta l^R_{j,t}$ means there is a greater default risk for home government bonds. $\Delta\lambda_{j,t}$ is the residual measure of the change in the home relative to foreign liquidity yields, and for that we posit a negative value of β_2. As in our model, we should also find negative values for the estimates of β_1 and β_5.

[24] Details of the full derivation of these expressions are available at Du, et al. (2018a).

We estimate the regression in two ways. First, since CDS data for many of the sample countries are only available after 2008, we start the sample from 2008M1 and estimate (24). Second, to make use of the full sample information and test whether the adjusted liquidity measure is important in explaining the change of exchange rates throughout the sample, we estimate the regression from 1999M1, but excluding the CDS data (dropping $\Delta l^R_{j,t}$ and $l^R_{j,t-1}$).[25]

In Table 3A, the coefficient estimates on $\Delta\lambda_{i,t}$, which represents the effect of changes in government bond liquidity after adjusting for credit risk and derivative market friction, are still significantly negative in all cases. The range of coefficient is from -3.04 to -8.91 for the left panel, indicating a monthly 3.04% to 8.91% immediate home currency appreciation when there is a monthly positive change of 100 basis points (annualized rate) in relative liquidity. These coefficients are also larger than the coefficients of $\Delta\eta_{i,t}$ estimated in Table 2A or Table 2C. These results reaffirm our baseline result that there is a strong linkage between government bond liquidity and exchange rates.

In many cases, we also see that credit risk variation and derivative market frictions are important variables in explaining the change of exchange rates.[26] The positive coefficient on $\Delta l^R_{j,t+1}$ indicates that an increase in home default risk relative to foreign default risk is associated with an immediate home currency depreciation. Holding the nominal government bond interest rate fixed, an increase in default risk implies the default risk adjusted nominal interest rate goes down, resulting in a home currency depreciation.

There are two ways we could interpret the negative coefficient on $\Delta\tau_{j,t}$. First, the channel could go through the change in $IRS^*_{j,t} - IRS_t$. If there is default risk in the IRS contract an increase in the home IRS rate drives a home currency depreciation. Second, the channel could go through the change in $f_{t,t+1} - s_t$. In the case in which $\Delta\tau_{j,t}$ is positive, market conditions are now more favorable to borrow in home currency and construct a synthetic home market bond than before. As explained by Du, et al. (2018b), this could be the case that when there is excess international demand for both the home assets and forward contracts to hedge exchange rate risk in investing in

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25 In the second case, the $\lambda_{j,t}$ is effectively $\eta_{j,t} - \tau_{j,t}$

26 See Della Corte, et al. (2018) who find similar findings of the relationship between exchange rate and sovereign risk.

home assets, therefore the financial intermediaries have to mark up the forward rate $f_{t,t+1}$, as issuing a forward contract is costly for them. This mark-up of the forward rate then goes hand in hand with a strong home currency that is driven by excess international demand.

To confirm our results are robust to different specifications, we conduct the estimation in (24) by including one or two sub-components at a time. The results are reported at Table 3B. Once again, we find the regression coefficients for $\Delta\lambda_{j,t}$ are significantly negative in all cases.

How much of the variation of η_t is driven by each of the sub-components? We can answer this with a variance decomposition. Table 3C reports the decomposition given by:

$$(25) \quad 1 = \frac{\text{var}(\Delta\lambda_t)}{\text{var}(\Delta\eta_t)} + \frac{\text{var}(\Delta\tau_t)}{\text{var}(\Delta\eta_t)} + \frac{\text{var}(\Delta l_t^R)}{\text{var}(\Delta\eta_t)} + 2\frac{\text{cov}(\Delta\lambda_t, \Delta\tau_t)}{\text{var}(\Delta\eta_t)} - 2\frac{\text{cov}(\Delta\tau_t, \Delta l_t^R)}{\text{var}(\Delta\eta_t)} - 2\frac{\text{cov}(\Delta l_t^R, \Delta\lambda_t)}{\text{var}(\Delta\eta_t)}$$

For most of the countries, the variation of $\Delta\lambda_t$ contributes a large share of variation of $\Delta\eta_t$. However, the sums of the variance shares of $\Delta\lambda_t$, $\Delta\tau_t$, and Δl_t^R are greater than one. This arises because Δl_t^R is positively correlated with $\Delta\lambda_t$ (and Δl_t^R enters the expression for $\Delta\eta_t$ with a negative sign in equation (22)), and because $\Delta\lambda_t$ and $\Delta\tau_t$ are negatively correlated for most countries. Because all three components contribute to the variation in $\Delta\eta_t$, it is important to clarify the role of each in driving changes in currency values. In this section, we have seen that even controlling for default and swap-market frictions, the liquidity yield is still a significant determinant of exchange rates.

Instrumental variable regressions

The empirical analysis above shows a strong relation between relative government bond liquidity and the exchange rate. In this subsection, we instrument for the liquidity returns, which allows us to give a causal interpretation – that a change in the relative government bond liquidity leads to a change in the bilateral exchange rates.

As we have already discussed in the introduction, government bonds are more valuable than similar marketable securities because of their safety and liquidity. Our first set of instruments are measures of changes in global uncertainty. In the face of this uncertainty, there may be a safe-haven demand of government bonds which is reflected in the relative liquidity return. We use several different measures of global uncertainty: the log of VIX, log of the gold price, G10 cross-country average square inflation rates, G10 cross-country average unemployment rates, G10 cross-country average square of change in bilateral exchange rates and G10 cross-country average absolute change of bilateral exchange rates. The VIX and gold price are well-known measures for global uncertainty. The other four variables are meant to capture the fact that when global uncertainty is high, inflation, unemployment and exchange rate volatility tend to be high as well. We posit that these cross-country instruments are exogenous to bilateral exchange rate movements because of their "global" nature. That is, we hypothesize that the channel through which global uncertainty affects the value of one currency relative to another is the relative government bond premium.

Our second set of instruments gauges the scarcity of liquid assets available in an economy. We adopt general government debt to GDP for each country as an instrument. The smaller general government debt, the more valued at the margin those instruments are for their liquidity services, hence they pay a higher liquidity yield. Our underlying assumption is that the general government debt to GDP ratio influences exchange rate movements only through their liquidity effect. The sample of countries we considered are developed economies with independent fiscal policy and monetary policy, so it is not the case that there is fiscal dominance that determines inflation and currency values.

Specifically, we conducted the same panel fixed-effect regressions as in (20) and (24) but we instrument the variables $\Delta\eta_{j,t}$, $\eta_{j,t-1}$ in (20) and $\Delta\lambda_{j,t}$, $\lambda_{j,t-1}$ in (24) by the level and the change of the instruments discussed above.[27] We present three different specifications in Table 4A to 4C. In table 4A, the variable $\Delta\eta_{j,t}$, $\eta_{j,t-1}$ in (20) are instrumented. The lagged real exchange rates and change in interest rate differential are universally negatively significant, which is consistent with what we found earlier. The instrumented change of government bond liquidity has a negative coefficient in 8 out of the 10 regressions and significantly negative in 7 of them.

In table 4B and 4C, the variables $\Delta\lambda_{j,t}$, $\lambda_{j,t-1}$ in (24) are instrumented. For the same reason discussed above for estimating (24), we estimate the regression in two ways. We estimate

[27] Whenever needed, we linear interpolate the instruments in the first stage regressions.

the regression from 1999M1 in table 4B, but excluding the CDS data (dropping $\Delta l^R_{j,t}$ and $l^R_{j,t-1}$) and we estimate (24) from 2008M1 in table 4C, with the CDS adjustments. The instrumented change of government bond liquidity are negatively significant in 7 out of the 10 and 9 out of the 10 countries respectively. Overall, we find that the instrumental variable regressions are consistent with what we find in the baseline result and offer empirical support of the causal relationship that a change in relative government bond liquidity causes exchange rate movements.

3.4 Country-specific Government Bond Liquidity

So far, we have conducted all our analysis with different measures of bilateral relative government bond liquidity. However, the impact of the own-country liquidity service and the aggregate foreign country liquidity service might have different effects on the home exchange rate.

We measure the home and foreign liquidity returns on government bonds as $\gamma_t = IRS_t - i_t$ and $\gamma^*_{j,t} = IRS^*_t - i^*_t$. Motivated by the decomposition above, we will include also the currency derivative market friction, $\tau_{j,t}$. We have then that $\eta_{j,t}$ used in our baseline regressions can be decomposed as:

(26) $$\eta_{j,t} = \tau_{j,t} + \gamma_t - \gamma^*_{j,t}$$

We estimate the following equation with the country specific liquidity measures, controlling for the derivative market friction:

(27)

$$\Delta s_{j,t} = \alpha_j + \beta_1 q_{j,t-1} + \beta_2 \Delta \tau_{j,t} + \beta_3 \Delta \gamma_t + \beta_4 \Delta \gamma^*_{j,t} + \beta_5 \Delta i^R_{j,t} + \beta_6 \tau_{t-1} + \beta_7 \gamma_{t-1} + \beta_8 \gamma^*_{j,t-1} + \beta_9 i^R_{j,t-1} + u_{j,t}$$

Estimates of β_3 and β_4 in (27) show how the change of country-specific government bond liquidity affects exchange rate movements. We expect a negative sign for β_3 and a positive sign for β_4.

Table 5A presents the estimation results for the country specific government bond liquidity. The second column gives the coefficient estimates for the change in government bond liquidity for all the foreign currencies. The coefficient estimates are all significantly positive, indicating an increase in government bond liquidity of the foreign country is associated with a depreciation of the home currency, which is consistent with our theory and the empirical finding above. All the coefficient estimates of the home government bond liquidity, $\Delta\gamma_t$, term are significantly negative with the exception of the Japanese Yen and Swiss Franc. Both estimates are negative but with smaller absolute size compared to others.

These results then show that our findings regarding the effect of the relative liquidity returns on exchange rates are, for each country, driven at least in part by the liquidity return of that country. That is, the effects on exchange rates of the relative liquidity returns are not all determined by liquidity returns in one or a few larger countries.

We provide further evidence that our findings are not driven by one or a few countries by performing our baseline regression (20) country-by-country. Table 5B provides a summary of those regression results. (We report all 45 country-by-country regressions in the Supplementary Appendix.) For the analysis that uses the entire 1999-2017 sample, among the 45 country pairs, 37 country pairs have coefficients on $\Delta\eta_t$ that are negatively statistically different from zero at the 10% level. We find that 42 of the 45 pairs have a negatively significant coefficient on Δi_t^R at the 1% level. This evidence makes manifest that our results are not driven by a single country. Country-by-country regressions also allow the coefficients to be unconstrained and leave room for higher explanatory power. While the median adjusted R-squared of the full sample regressions (17%) is close to the average R-squared of the panel regressions, the maximum adjusted R-squared is 33% for the full sample and 49% post-2008 (in both cases for the AUD-JPY pair).

3.5 Out-of-sample fit

The influential work by Meese and Rogoff (1983) shows that standard macroeconomic exchange rate models, even with the aid of ex post data on the fundamentals, forecast exchange rates at short to medium horizons no better than a random walk. In this subsection, we conduct an out-of-sample forecasting exercise as in Meese and Rogoff (1983) and find that our empirical model significantly outperforms the random walk prediction.

We estimate (21), the model with only interest rate differential and the lagged real exchange rate as explanatory variables, and (20), the empirical model that also includes the liquidity return, using a rolling regression approach.[28] We first use the sample from 1999M1 to 2007M12 for the estimation of regression coefficients. The rolling window is therefore 108 months and the forecast horizon is one month. The first prediction is 2008M1 and the last prediction is 2017M12. We then compare the root-mean-square-error (RMSE) of these models verse the RMSE of a random walk no change prediction ($\Delta\hat{s}_{j,t}^{RW} = 0$). As in the Meese-Rogoff exercise, we use actual realized values of the right-hand-side variables to generate the forecasts.

Table 6 reports the RMSEs of the predictions of models (20), (21) and the random walk prediction. The RMSEs of forecasts from (20) and (21) are lower than the RMSEs of the random walk prediction in 9 out of the 10 countries. We are also interested in testing whether these differences in RMSEs are statistically significant. We adopt the test statistics by Diebold and Mariano (1995) and West (1996) (DMW) which tests the following three null hypothesis: A) mean-square-error (MSE) of the prediction model (21) and the random walk model are equal, B) MSE of the prediction model (20) and the random walk model are equal and C) MSE of the prediction model (21) and MSE of the prediction model (20) are equal. The DMW statistics are reported in column (5)-(7) in Table 6. Since model (20) nests model (21) and the random walk model, Clark and West (2006) shows that the DMW test statistic should be corrected to account for the fact the regression coefficients are estimated. The Clark-West adjusted test statistic (CW statistics) is asymptotically standard normal and suitable for usual statistics inference. We report the CW statistics and the corresponding p-value of the one-sided alternative test in columns (8)-(14). We find that the prediction model (21), which includes only the lagged real exchange rate and the interest-rate differential, performs significantly better than random walk in 9 out of the 10 cases (p-values in column (9).) We find the baseline model with liquidity returns, (20), outperforms the random walk model in all cases (p values in column (12).) In all cases, we find that the MSE of model (20) are significantly lower than model (21) (p-values in column (14).)

[28] We also estimate using a recursive regression approach. The results are robustness to the recursive specification and are reported in the Supplementary Appendix.

Thus, the random-walk model and the model that does not include liquidity returns are rejected in favor of our baseline model for all currencies using the Meese-Rogoff criterion.

Switzerland, January 2015

The model with the liquidity yield included significantly outperforms the random walk model and the traditional model for all currencies, but the RMSE for both the liquidity model and the traditional model are higher than the random walk for the single exception of Switzerland.[29] If we eliminate one month from the Swiss sample, January 2015, the models also have lower RMSEs than the random walk.

Until that month, the Swiss National Bank had been trying to keep the Swiss franc from appreciating, setting very low interest rates and engaging in massive foreign exchange intervention to keep a ceiling on the value of the franc of CHF1.20 per euro. The SNB lifted the cap in January 2015, which led to a very large franc appreciation that month, despite the low Swiss interest rates. The model performs poorly in that month because the low interest rates should have led to a depreciation of the franc, as the SNB desired.[30]

In fact, all of our results reported in previous table are improved, sometimes markedly, for the Swiss franc if that one month is eliminated from the sample. It is an extreme outlier. The absolute value of the change in the log of the exchange rate during that month is much greater than for any currency during any month, and it is also a month in which Swiss interest rates were at extremely low values. In particular, in a few of the regressions reported above, the sign on the interest differential was positive rather than negative for Switzerland, but that anomaly disappears when January, 2015 is dropped from the sample.

4. Conclusions

Our empirical findings are good news for macroeconomic models of exchange rates. The government liquidity yield is the "missing link" in exchange rate determination. Not only do we find that liquidity yields are a significant determinant of exchange rate movements for all of the

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[29] Note that because the CW statistic takes into account estimation error, both models are found to have a significantly better fit than the random walk, even including January 2015, even though their RMSEs are higher than the random walk model's RMSE.

[30] In the Supplementary Appendix, we report the results with the extreme outlier in January 2015 dropped.

largest countries, but we also find that with these included, traditional determinants of exchange rate movements are also important. Our simple regressions have high R-squared values, so can account for a large fraction of exchange rate movements. In short, exchange rates are not so disconnected after all.

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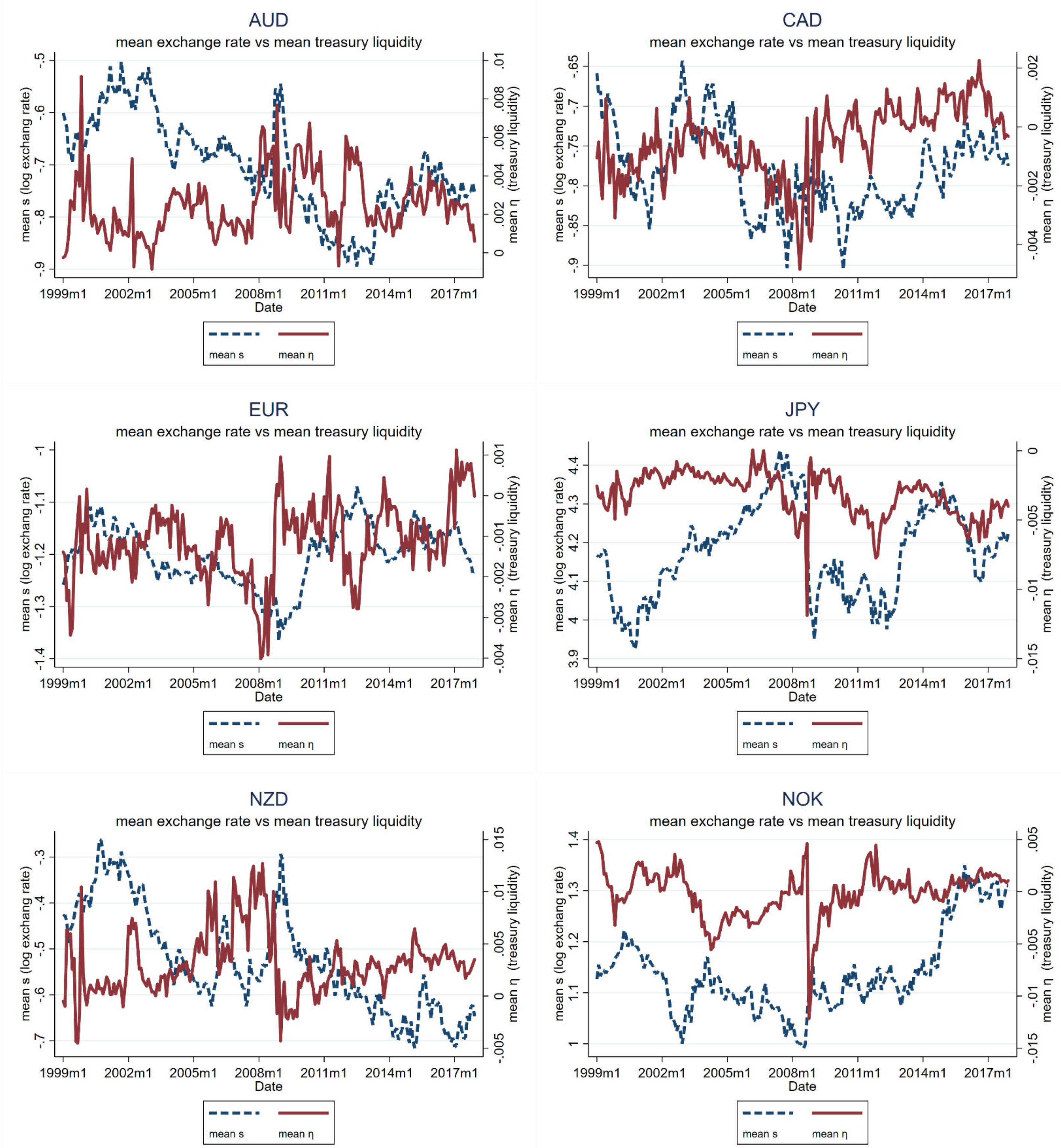
Figure 1:



(Figure 1 continued)

Figure 1 continue

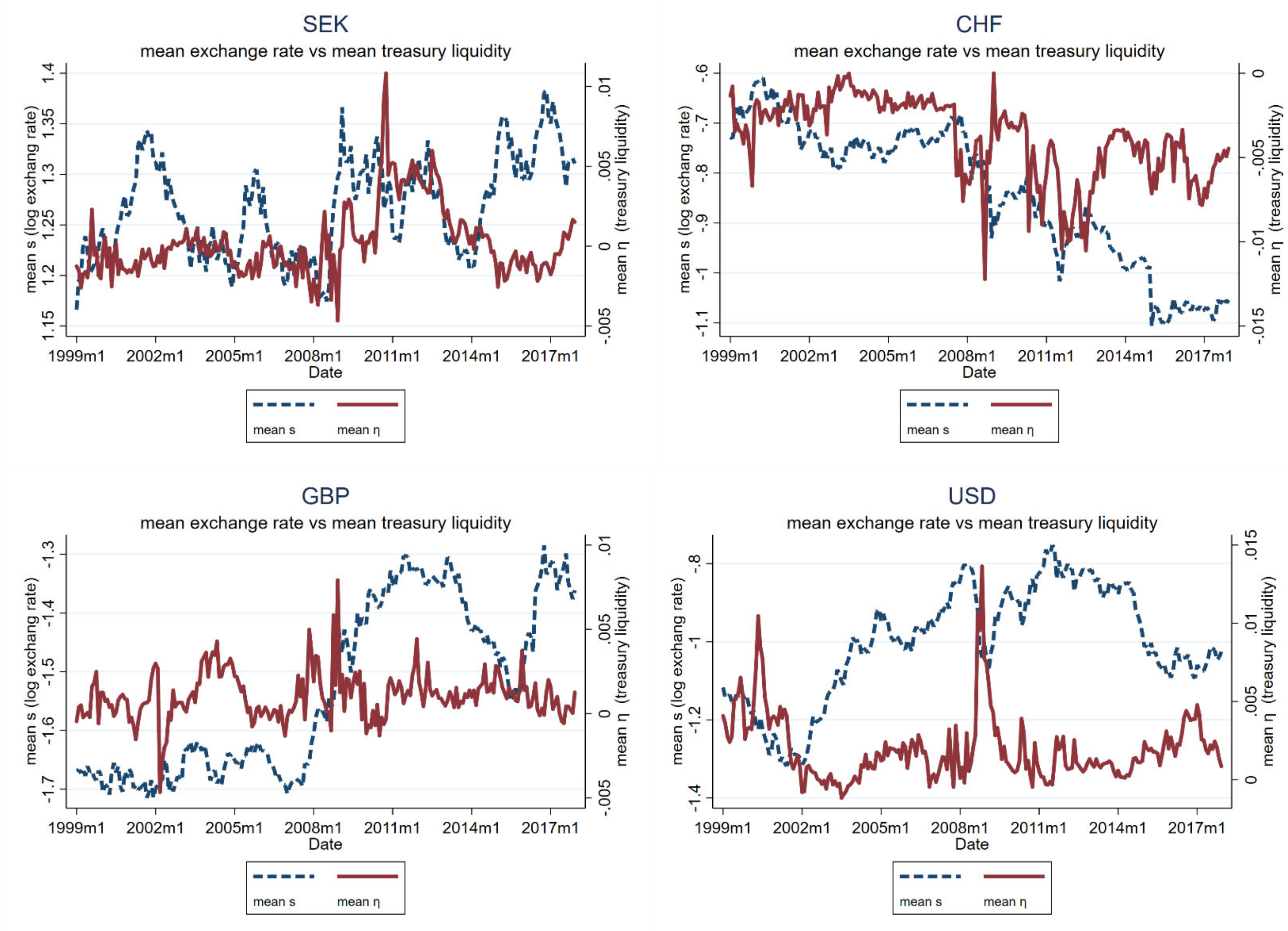


Table 1:

Correlation of η_t and $i_t - i_t^*$

Home Currency	Correlation of η_t and $i_t - i_t^*$
AUD	0.4637
CAD	0.5054
EUR	0.4841
JPY	0.1284
NZD	0.3894
NOK	0.5089
SEK	0.4673
CHF	0.1977
GBP	0.4269
USD	0.5202

The 10 currencies used are Australian Dollar (AUD), Canadian Dollar (CAD), Euro (EUR), Japanese Yen (JPY), New Zealand Dollar (NZD), Norwegian Krone (NOK), Swedish Krona (SEK), Swiss Franc (CHF), British Pound (GBP) and United States Dollar (USD). The correlation is calculated for each home currency *i* and foreign currency *j*. The sample period is 1999M1-2017M12. Germany government interest rate is used for EUR case.

Table 2A:
Estimation result of $\Delta s_{j,t} = \alpha_j + \beta_1 q_{j,t-1} + \beta_2 \Delta\eta_{j,t} + \beta_3 \Delta i^R_{j,t} + \beta_4 \eta_{j,t-1} + \beta_5 i^R_{j,t-1} + u_{j,t}$

Home Currency (1)	$q_{i,t-1}$ (2)	$\Delta\eta_{j,t}$ (3)	$\Delta i^R_{j,t}$ (4)	Observations (5)	Within R^2 (6)
AUD	-0.0284***	-5.2710***	-5.7441***	2052	0.1891
	(0.0071)	(0.7181)	(0.5356)		
CAD	-0.0267***	-4.6086***	-5.4603***	2052	0.1723
	(0.0062)	(0.6238)	(0.4910)		
EUR	-0.0203***	-4.6406***	-5.0187***	2052	0.1434
	(0.0059)	(0.5179)	(0.4103)		
JPY	-0.0400***	-4.3863***	-6.3171***	2052	0.1692
	(0.0102)	(0.9532)	(0.7367)		
NZD	-0.0276***	-6.2906***	-6.0200***	2052	0.1955
	(0.0082)	(0.7275)	(0.6082)		
NOK	-0.0190***	-4.0106***	-4.8711***	2052	0.1537
	(0.0068)	(0.6138)	(0.4877)		
SEK	-0.0226***	-4.5193***	-4.5991***	2052	0.1315
	(0.0062)	(0.5796)	(0.4631)		
CHF	-0.0129**	-2.3197***	-2.7587***	2052	0.0509
	(0.0065)	(0.7129)	(0.5557)		
GBP	-0.0227***	-3.3495***	-5.2385***	2052	0.1283
	(0.0067)	(0.6655)	(0.5212)		
USD	-0.0113*	-6.4388***	-4.7717***	2052	0.1689
	(0.0068)	(0.7198)	(0.5691)		

The table reports the OLS estimates of the coefficient of the panel fixed effect regression listed above. The 10 currencies used are Australian Dollar (AUD), Canadian Dollar (CAD), Euro (EUR), Japanese Yen (JPY), New Zealand Dollar (NZD), Norwegian Krone (NOK), Swedish Krona (SEK), Swiss Franc (CHF), British Pound (GBP) and United States Dollar (USD). Each row represents a regression estimation using the column (1) currency as the home currency and the other 9 currencies as foreign currency j. $s_{j,t}$ is the nominal exchange rate between home and foreign country j, defined as home currency price of foreign currency, $q_{j,t}$ is the real exchange rate. η_t is the measure of government bond liquidity, $i^R_{j,t}$ is the home minus foreign interest rates. $\Delta$is a difference operator. The sample period is 1999M1-2017M12. Germany government interest rate is used for EUR case.
Standard errors in parentheses are standard errors adjusted for cross-sectional correlation. *, **, and *** indicate that the alternative model significantly different from zero at 10%, 5%, and 1% significance level, respectively, based on standard normal critical values for the two-sided test. *, **, and *** for $q_{j,t}$ is based on critical values from distribution for Augmented Dickey Fuller test with a constant.
The table only reports the coefficient estimates of interest. A table that reports all coefficient estimates is available in the supplementary appendix.

Table 2B:

Estimation result of $\Delta s_{j,t} = \alpha_j + \beta_1 q_{j,t-1} + \beta_2 \Delta i^R_{j,t} + \beta_3 i^R_{j,t-1} + u_{j,t}$

Home Currency (1)	$q_{i,t-1}$ (2)	$\Delta i^R_{j,t}$ (3)	$i^R_{j,t}$ (4)	Observations (5)	Within R^2 (6)
AUD	-0.0316***	-4.0715***	-0.2823***	2052	0.1134
	(0.0074)	(0.5134)	(0.1087)		
CAD	-0.0276***	-4.5353***	-0.2493**	2052	0.1166
	(0.0064)	(0.4682)	(0.0985)		
EUR	-0.0226***	-3.8297***	-0.1958**	2052	0.0895
	(0.0060)	(0.3850)	(0.0909)		
JPY	-0.0340***	-5.3243***	-0.1493	2052	0.1000
	(0.0105)	(0.7255)	(0.1294)		
NZD	-0.0308***	-2.6695***	-0.0946	2052	0.0563
	(0.0093)	(0.5950)	(0.1333)		
NOK	-0.0177**	-3.4970***	-0.1255	2052	0.0820
	(0.0070)	(0.4693)	(0.0951)		
SEK	-0.0267***	-3.2092***	-0.1359	2052	0.0711
	(0.0063)	(0.4350)	(0.0983)		
CHF	-0.0097	-2.0012***	-0.2245**	2052	0.0239
	(0.0061)	(0.5164)	(0.1026)		
GBP	-0.0225***	-3.7205***	-0.3344***	2052	0.0856
	(0.0068)	(0.4902)	(0.0994)		
USD	-0.0141*	-3.6842***	-0.1376	2052	0.0684
	(0.0075)	(0.5813)	(0.1122)		

The table reports the OLS estimates of the coefficient of the panel fixed effect regression listed above. The 10 currencies used are Australian Dollar (AUD), Canadian Dollar (CAD), Euro (EUR), Japanese Yen (JPY), New Zealand Dollar (NZD), Norwegian Krone (NOK), Swedish Krona (SEK), Swiss Franc (CHF), British Pound (GBP) and United States Dollar (USD). Each row represents a regression estimation using the column (1) currency as the home currency and the other 9 currencies as foreign currency j. $s_{j,t}$ is the nominal exchange rate between home and foreign country j, defined as home currency price of foreign currency, $q_{j,t}$ is the real exchange rate. $i^R_{j,t}$ is the home minus foreign interest rates. $\Delta$is a difference operator. The sample period is 1999M1-2017M12. Germany government interest rate is used for EUR case.

Standard errors in parentheses are standard errors adjusted for cross-sectional correlation. *, **, and *** indicate that the alternative model significantly different from zero at 10%, 5%, and 1% significance level, respectively, based on standard normal critical values for the two-sided test. *, **, and *** for $q_{j,t}$ is based on critical values from distribution for Augmented Dickey Fuller test with a constant.

The table only reports the coefficient estimates of interest. A table that reports all coefficient estimates is available in the supplementary appendix.

Table 2C:
Estimation result of $\Delta s_{j,t} = \alpha_j + \beta_1 q_{j,t-1} + \beta_2 \Delta\eta_{j,t} + \beta_3 \Delta i^R_{j,t} + \beta_4 \eta_{j,t-1} + \beta_5 i^R_{j,t-1} + u_{j,t}$

Home Currency (1)	$\Delta\eta_{j,t}$ (2)	Within R^2 (3)	$\Delta\eta_{j,t}$ (4)	Within R^2 (5)
	1999M1-2007M12		2008M1-2017M12	
AUD	-3.7828***	0.0860	-6.0254***	0.2958
	(1.2048)		(0.8766)	
CAD	-2.7138**	0.0899	-5.7275***	0.2921
	(1.0860)		(0.7300)	
EUR	-2.8935***	0.0463	-5.2961***	0.2587
	(0.8520)		(0.6488)	
JPY	-1.1698	0.0413	-5.7308***	0.3300
	(1.3160)		(1.2351)	
NZD	-4.4680***	0.0987	-6.9225***	0.3205
	(1.1189)		(0.9474)	
NOK	-3.5820***	0.0890	-4.8783***	0.2584
	(0.9969)		(0.7696)	
SEK	-2.9760***	0.0743	-5.6023***	0.2276
	(0.9147)		(0.7307)	
CHF	-1.1317	0.0262	-2.8630***	0.0918
	(1.0144)		(1.0104)	
GBP	-4.1039***	0.0988	-3.4219***	0.2086
	(0.8843)		(0.9195)	
USD	-3.9766***	0.0791	-7.1136***	0.3262
	(1.1134)		(0.8594)	

The table reports the OLS estimates of the coefficient of the panel fixed effect regression listed above. The 10 currencies used are Australian Dollar (AUD), Canadian Dollar (CAD), Euro (EUR), Japanese Yen (JPY), New Zealand Dollar (NZD), Norwegian Krone (NOK), Swedish Krona (SEK), Swiss Franc (CHF), British Pound (GBP) and United States Dollar (USD). Each row represents a regression estimation using the column (1) currency as the home currency and the other 9 currencies as foreign currency j. $s_{j,t}$ is the nominal exchange rate between home and foreign country j, defined as home currency price of foreign currency, $q_{j,t}$ is the real exchange rate. η_t is the measure of government bond liquidity, $i^R_{j,t}$ is the home minus foreign interest rates. $\Delta$is a difference operator. The sample period is 1999M1-2007M12 and 2008M1-2017M12. Germany government interest rate is used for EUR case. Standard errors in parentheses are standard errors adjusted for cross-sectional correlation. *, **, and *** indicate that the alternative model significantly different from zero at 10%, 5%, and 1% significance level, respectively, based on standard normal critical values for the two-sided test. *, **, and *** for $q_{j,t}$ is based on critical values from distribution for Augmented Dickey Fuller test with a constant.
The table only reports the coefficient estimates of interest. A table that reports all coefficient estimates is available in the supplementary appendix.

Table 2D:

Estimation result of $\Delta s_{j,t} = \alpha_j + \beta_1 q_{j,t-1} + \beta_2 \Delta\eta_{j,t} + \beta_3 \Delta i^R_{j,t} + \beta_4 \eta_{j,t-1} + \beta_5 i^R_{j,t-1} + u_{j,t}$

using one-month forward rates and one-month government yields

Home Currency	$q_{i,t-1}$	$\Delta\eta_{j,t}$	$\Delta i^R_{j,t}$	Observations
(1)	(2)	(3)	(4)	(5)
AUD	-0.0543**	-7.2292	-22.9042	360
	(0.0259)	(10.5997)	(14.9001)	
CAD	-0.0299***	-12.7346***	-29.1263***	1228
	(0.0099)	(4.6383)	(7.2838)	
EUR	-0.0826***	-18.6085**	-20.0382**	609
	(0.0167)	(7.4739)	(9.0270)	
JPY	-0.1023***	-23.3412**	-11.6606	462
	(0.0237)	(10.1332)	(11.6918)	
NZD	-0.0331***	-18.7123***	-28.5861***	1228
	(0.0103)	(4.8520)	(6.9774)	
SEK	-0.0332***	-14.9686***	-17.2230***	1228
	(0.0085)	(3.8834)	(5.6090)	
CHF	-0.0572***	-10.8859	9.7523	731
	(0.0138)	(8.9118)	(8.5222)	
GBP	-0.0221*	-8.1728*	-19.2894***	1228
	(0.0115)	(4.9056)	(7.0342)	
USD	-0.0254***	-17.1716***	-15.1574**	1228
	(0.0088)	(3.9433)	(6.1518)	

The table reports the OLS estimates of the coefficient of the panel fixed effect regression listed above. The 10 currencies used are Australian Dollar (AUD), Canadian Dollar (CAD), Euro (EUR), Japanese Yen (JPY), New Zealand Dollar (NZD), Swedish Krona (SEK), Swiss Franc (CHF), British Pound (GBP) and United States Dollar (USD). Each row represents a regression estimation using the column (1) currency as the home currency and the other 9 currencies as foreign currency j. $s_{j,t}$ is the nominal exchange rate between home and foreign country j, defined as home currency price of foreign currency, $q_{j,t}$ is the real exchange rate. η_t is the measure of government bond liquidity, $i^R_{j,t}$ is the home minus foreign interest rates. $\Delta$is a difference operator. The sample period is 1999M1-2017M12. Germany government interest rate is used for EUR case.

Standard errors in parentheses are standard errors adjusted for cross-sectional correlation. *, **, and *** indicate that the alternative model significantly different from zero at 10%, 5%, and 1% significance level, respectively, based on standard normal critical values for the two-sided test. *, **, and *** for $q_{j,t}$ is based on critical values from distribution for Augmented Dickey Fuller test with a constant.

The table only reports the coefficient estimates of interest. A table that reports all coefficient estimates is available in the supplementary appendix.

Table 3A:
Estimation result of

$$\Delta s_{j,t} = \alpha_j + \beta_1 q_{j,t-1} + \beta_2 \Delta\lambda_{j,t} + \beta_3 \Delta\tau_{j,t} + \beta_4 \Delta l^R_{j,t} + \beta_5 \Delta i^R_{j,t} + \beta_6 \lambda_{j,t-1} + \beta_7 \tau_{j,t-1} + \beta_8 l^R_{j,t-1} + \beta_9 i^R_{j,t-1} + u_{j,t}$$

Home Currency (1)	$\Delta\lambda_{i,t}$ (2)	$\Delta\tau_{i,t}$ (3)	$\Delta\lambda_{i,t}$ (4)	$\Delta\tau_{i,t}$ (5)	$\Delta l_{i,t}$ (6)
	Full sample, no default risk		Post 2008, with default risk		
AUD	-6.1475***	-2.9797**	-7.0027***	-3.1133**	14.3663***
	(0.7910)	(1.2262)	(1.1219)	(1.5396)	(2.3547)
CAD	-4.6021***	-5.2004***	-8.8567***	-6.8906***	8.3213***
	(0.7235)	(1.1252)	(1.5154)	(1.7969)	(2.5681)
EUR	-4.6613***	-4.9050***	-6.0993***	-3.9164***	8.2139***
	(0.5684)	(0.8672)	(0.7990)	(0.9455)	(1.6760)
JPY	-4.1648***	-4.9939***	-6.7890***	-4.4253**	10.1977***
	(1.0016)	(1.5866)	(1.3763)	(1.8491)	(3.1745)
NZD	-6.6165***	-5.7714***	-7.7871***	-5.8429***	12.2542***
	(0.7968)	(1.2968)	(1.1415)	(1.4849)	(2.5075)
NOK	-3.8436***	-5.0816***	-5.1123***	-5.7420***	4.0843**
	(0.6526)	(1.0437)	(0.8095)	(1.2013)	(1.9590)
SEK	-4.4583***	-5.0234***	-5.5565***	-4.1789***	7.4308***
	(0.6435)	(0.9849)	(0.8854)	(1.1469)	(1.9029)
CHF	-3.0442***	-1.1689	-3.2384**	-1.1997	5.6024**
	(0.7725)	(1.1966)	(1.4895)	(1.8080)	(2.6065)
GBP	-4.1890***	-1.4009	-6.1288***	-0.4453	5.6119**
	(0.7457)	(1.1224)	(1.1158)	(1.4105)	(2.3529)
USD	-6.3166***	-6.7369***	-8.9086***	-3.2019**	12.5574***
	(0.8213)	(1.1889)	(1.1126)	(1.2482)	(2.1570)

The table reports the OLS estimates of the coefficient of the panel fixed effect regression listed above. The 10 currencies used are Australian Dollar (AUD), Canadian Dollar (CAD), Euro (EUR), Japanese Yen (JPY), New Zealand Dollar (NZD), Norwegian Krone (NOK), Swedish Krona (SEK), Swiss Franc (CHF), British Pound (GBP) and United States Dollar (USD). Each row represents a regression estimation using the column (1) currency as the home currency and the other 9 currencies as foreign currency j. $s_{j,t}$ is the nominal exchange rate between home and foreign country j, defined as home currency price of foreign currency, $q_{j,t}$ is the real exchange rate. $\tau_{j,t}$ is the measure of currency derivative friction, $l^R_{j,t}$ is the measure of home minus foreign default risk, $\lambda_{j,t}$ is the measure of the government bond liquidity after adjusting for derivative market friction and default risk, $i^R_{j,t}$ is the home minus foreign interest rates. $\Delta$is a difference operator. The sample period is 1999M1-2017M12 (column (2) and (3)) and 2008M1-2017M12 (column (4) to (6)). Germany government interest rate and default risk are used for EUR case.

Standard errors in parentheses are standard errors adjusted for cross-sectional correlation. *, **, and *** indicate that the alternative model significantly different from zero at 10%, 5%, and 1% significance level, respectively, based on standard normal critical values for the two-sided test.

The table only reports the coefficient estimates of interest. A table that reports all coefficient estimates is available in the supplementary appendix.

Table 3B

Estimation result of $\Delta s_{j,t} = \alpha_j + \beta_1 q_{j,t-1} + \beta_2 \Delta X_{j,t} + \beta_3 \Delta i^R_{j,t} + \beta_4 X_{j,t-1} + \beta_5 i^R_{j,t-1} + u_{j,t}$

where $X_{j,t}$ is the column head variable

Home Currency	$\Delta\lambda_{j,t}$	$\Delta\tau_{j,t}$	$\Delta l^R_{j,t}$	$\Delta(\eta + l^R)_{j,t}$	$\Delta(\eta-\tau)_{j,t}$	$\Delta(\tau - l^R)_{j,t}$
(1)	(2)	(3)	(4)	(5)	(6)	(7)
AUD	-4.3320***	-1.4191	9.9450***	-4.2517***	-5.8403***	-4.6466***
	(1.0848)	(1.2782)	(2.2182)	(0.9598)	(0.7792)	(1.3055)
CAD	-3.6265***	-4.3619***	0.7547	-5.2887***	-3.6792***	-1.8207
	(1.3326)	(1.1244)	(2.2708)	(1.2257)	(0.7446)	(1.4376)
EUR	-3.1217***	-3.1629***	2.0777	-3.7550***	-3.5247***	-2.3862***
	(0.7396)	(0.8745)	(1.5476)	(0.6173)	(0.5774)	(0.8126)
JPY	-4.8998***	-5.8142***	4.5740	-4.5229***	-4.1970***	-6.1640***
	(1.3625)	(1.6352)	(3.1035)	(1.1374)	(1.0210)	(1.6355)
NZD	-4.9252***	-4.0584***	4.5388*	-5.1871***	-6.0615***	-5.2129***
	(1.1290)	(1.4135)	(2.5778)	(0.9127)	(0.8071)	(1.3696)
NOK	-4.1387***	-3.0231***	-1.2069	-4.7337***	-2.8878***	-3.3848***
	(0.7748)	(1.0557)	(1.9480)	(0.6652)	(0.6514)	(1.0826)
SEK	-4.0382***	-4.3694***	3.0840*	-4.1673***	-4.2018***	-3.7094***
	(0.8195)	(0.9940)	(1.8008)	(0.6806)	(0.6442)	(0.9927)
CHF	-1.7916	-1.4794	2.4456	-1.5402	-3.1277***	-2.0616
	(1.3227)	(1.2040)	(2.2902)	(1.0703)	(0.7759)	(1.4542)
GBP	-5.0370***	-0.6742	0.7847	-3.3605***	-4.0860***	-0.4514
	(1.0264)	(1.1406)	(2.2277)	(0.8669)	(0.7353)	(1.2028)
USD	-5.1253***	-6.1304***	5.1429**	-4.5722***	-6.0432***	-4.6762***
	(1.1080)	(1.2345)	(2.1134)	(0.8519)	(0.8433)	(1.1607)

The table reports the OLS estimates of the coefficient of change of liquidity measure of the regression listed above. The 10 currencies used are Australian Dollar (AUD), Canadian Dollar (CAD), Euro (EUR), Japanese Yen (JPY), New Zealand Dollar (NZD), Norwegian Krone (NOK), Swedish Krona (SEK), Swiss Franc (CHF), British Pound (GBP) and United States Dollar (USD). Each row represents a regression estimation using the column (1) currency as the home currency and the other 9 currencies as foreign currency j. $s_{j,t}$ is the nominal exchange rate between home and foreign country j, defined as home currency price of foreign currency, $q_{j,t}$ is the real exchange rate. $\tau_{j,t}$ is the measure of currency derivative friction, $l^R_{j,t}$ is the measure of home minus foreign default risk, $\lambda_{j,t}$ is the measure of the government bond liquidity after adjusting for derivative market friction and default risk, $i^R_{j,t}$ is the home minus foreign interest rates. $\Delta$is a difference operator. The sample period is 1999M1-2017M12. Regressions involving default risk $l^R_{j,t}$ are only estimated through 2008M1-2017M12 period (column (2), (4), (5),(7)). Germany default risk is used for EUR case.

Standard errors in parentheses are standard errors adjusted for cross-sectional correlation. *, **, and *** indicate that the alternative model significantly different from zero at 10%, 5%, and 1% significance level, respectively, based on standard normal critical values for the two-sided test.

The table only reports the coefficient estimates of interest. A table that reports all coefficient estimates is available in the supplementary appendix.

Table 3C

$$1=\frac{\text{var}(\Delta\lambda_t)}{\text{var}(\Delta\eta_t)}+\frac{\text{var}(\Delta\tau_t)}{\text{var}(\Delta\eta_t)}+\frac{\text{var}(\Delta l_t^R)}{\text{var}(\Delta\eta_t)}+2\frac{\text{cov}(\Delta\lambda_t,\Delta\tau_t)}{\text{var}(\Delta\eta_t)}-2\frac{\text{cov}(\Delta\tau_t,\Delta l_t^R)}{\text{var}(\Delta\eta_t)}-2\frac{\text{cov}(\Delta l_t^R,\Delta\lambda_t)}{\text{var}(\Delta\eta_t)}$$

Variance share of each of the terms above:

Home Currency	$\frac{\text{var}(\Delta\lambda_t)}{\text{var}(\Delta\eta_t)}$	$\frac{\text{var}(\Delta\tau_t)}{\text{var}(\Delta\eta_t)}$	$\frac{\text{var}(\Delta l_t^R)}{\text{var}(\Delta\eta_t)}$	$\frac{2\text{cov}(\Delta\lambda_t,\Delta\tau_t)}{\text{var}(\Delta\eta_t)}$	$\frac{2\text{cov}(\Delta\tau_t,\Delta l_t^R)}{\text{var}(\Delta\eta_t)}$	$\frac{2\text{cov}(\Delta l_t^R,\Delta\lambda_t)}{\text{var}(\Delta\eta_t)}$
(1)	(2)	(3)	(4)	(5)	(6)	(7)
AUD	73%	36%	13%	-7%	-4%	19%
CAD	139%	55%	56%	-46%	-6%	109%
EUR	119%	54%	22%	-50%	-7%	53%
JPY	64%	37%	15%	12%	1%	27%
NZD	80%	39%	12%	-5%	1%	26%
NOK	96%	25%	9%	-10%	2%	17%
SEK	87%	26%	14%	0%	-3%	32%
CHF	67%	42%	18%	12%	1%	38%
GBP	80%	36%	16%	-6%	1%	26%
USD	73%	39%	25%	4%	0%	41%

The 10 currencies used are Australian Dollar (AUD), Canadian Dollar (CAD), Euro (EUR), Japanese Yen (JPY), New Zealand Dollar (NZD), Norwegian Krone (NOK), Swedish Krona (SEK), Swiss Franc (CHF), British Pound (GBP) and United States Dollar (USD). Each row represents the variance and covariance using the column (1) currency as the home currency and the other 9 currencies as foreign currency j. η is the measure of government bond liquidity, $\tau_{j,t}$ is the measure of currency derivative friction, $l_{j,t}^R$ is the measure of home minus foreign default risk, $\lambda_{j,t}$ is the measure of the government bond liquidity after adjusting for derivative market friction and default risk, $i_{j,t}^R$ is the home minus foreign interest rates. Δ is a difference operator. The sample period is 2008M1-2017M12. Germany default risk and government interest rate are used for EUR case.

Table 4A:

IV Estimation result of $\Delta s_{j,t} = \alpha_j + \beta_1 q_{j,t-1} + \beta_2 \Delta\eta^{IV}_{j,t} + \beta_3 \Delta i^R_{j,t} + \beta_4 \eta^{IV}_{j,t-1} + \beta_5 i^R_{j,t-1} + u_{j,t}$

Home Currency (1)	$q_{j,t-1}$ (2)	$\Delta\eta^{IV}_{j,t}$ (3)	$\Delta i^R_{j,t}$ (4)	Observations (5)
AUD	-0.0200**	-16.8727***	-8.8118***	1974
	(0.0084)	(3.8681)	(1.1869)	
CAD	-0.0281***	-7.0227*	-6.1355***	1974
	(0.0070)	(3.7557)	(0.8876)	
EUR	-0.0261***	2.7898	-3.8749***	1890
	(0.0073)	(4.3529)	(0.9843)	
JPY	-0.0429***	-10.3487***	-7.6512***	1974
	(0.0113)	(2.5929)	(0.8700)	
NZD	-0.0258***	-6.9143**	-6.9147***	1974
	(0.0085)	(3.0244)	(1.5137)	
NOK	-0.0283***	-3.2652**	-5.3720***	1890
	(0.0082)	(1.4336)	(0.6522)	
SEK	-0.0186***	-9.7381***	-6.2327***	1974
	(0.0069)	(2.5794)	(0.9620)	
CHF	-0.0244***	0.0340	-2.4110***	1974
	(0.0074)	(2.2601)	(0.8263)	
GBP	-0.0324***	-1.7451	-6.0530***	1890
	(0.0088)	(3.2336)	(1.2756)	
USD	-0.0133*	-9.0688***	-4.8457***	1974
	(0.0072)	(2.3354)	(0.7826)	

The table reports the OLS estimates of the coefficient of the panel fixed effect regression listed above. The 10 currencies used are Australian Dollar (AUD), Canadian Dollar (CAD), Euro (EUR), Japanese Yen (JPY), New Zealand Dollar (NZD), Norwegian Krone (NOK), Swedish Krona (SEK), Swiss Franc (CHF), British Pound (GBP) and United States Dollar (USD). Each row represents a regression estimation using the column (1) currency as the home currency and the other 9 currencies as foreign currency j. $s_{j,t}$ is the nominal exchange rate between home and foreign country j, defined as home currency price of foreign currency, $q_{j,t}$ is the real exchange rate. $\eta^{IV}_{j,t}$ is the instrumented measure of government bond liquidity, $i^R_{j,t}$ is the home minus foreign interest rates.

Δ is a difference operator. The instruments for government bond liquidity are change and the level of log of general government debt to GDP for home country and each foreign country j, log of the VIX index, log of the gold price, G10 cross-country average square inflation rates, G10 cross-country average unemployment rates, G10 cross-country average square of change in bilateral exchange rates and G10 cross-country average absolute change of bilateral exchange rates.. The sample period is 1999M1-2017M12. Germany government interest rate and debt to GDP are used for EUR case.

Standard errors in parentheses are standard errors adjusted for cross-sectional correlation. *, **, and *** indicate that the alternative model significantly different from zero at 10%, 5%, and 1% significance level, respectively, based on standard normal critical values for the two-sided test. *, **, and *** for $q_{j,t}$ is based on critical values from distribution for Augmented Dickey Fuller test with a constant.

The table only reports the coefficient estimates of interest. A table that reports all coefficient estimates is available in the supplementary appendix.

Table 4B:
IV Estimation result of

$$\Delta s_{j,t} = \alpha_j + \beta_1 q_{j,t-1} + \beta_2 \Delta\lambda^{IV}_{j,t} + \beta_3 \Delta i^R_{j,t} + \beta_4 \Delta\tau_{j,t} + \beta_5 \lambda^{IV}_{j,t-1} + \beta_6 i^R_{j,t-1} + \beta_7 \tau_{j,t-1} + u_{j,t}$$

Home Currency (1)	$q_{j,t-1}$ (2)	$\Delta\lambda^{IV}_{j,t}$ (3)	$\Delta i^R_{j,t}$ (4)	Observations (5)
AUD	-0.0134	-24.4061***	-9.8132***	1950
	(0.0091)	(4.8670)	(1.2647)	
CAD	-0.0333***	1.6306	-5.1841***	1797
	(0.0079)	(6.0219)	(1.2146)	
EUR	-0.0188***	-12.9225***	-7.3831***	1879
	(0.0069)	(4.9583)	(1.3063)	
JPY	-0.0463***	-13.1779***	-8.2092***	1950
	(0.0110)	(3.9153)	(1.0604)	
NZD	-0.0282***	-4.7995	-6.0322***	1950
	(0.0082)	(3.3147)	(1.5542)	
NOK	-0.0275***	-3.3757**	-5.4678***	1879
	(0.0079)	(1.4260)	(0.6378)	
SEK	-0.0193***	-8.7994***	-5.9130***	1950
	(0.0068)	(2.8957)	(1.0111)	
CHF	-0.0193***	-3.4301	-3.4869***	1950
	(0.0070)	(3.6665)	(1.2207)	
GBP	-0.0269***	-13.1736***	-9.8183***	1879
	(0.0088)	(4.5239)	(1.6896)	
USD	-0.0139*	-13.1999***	-5.7265***	1950
	(0.0074)	(3.1698)	(0.9184)	

The table reports the OLS estimates of the coefficient of the panel fixed effect regression listed above. The 10 currencies used are Australian Dollar (AUD), Canadian Dollar (CAD), Euro (EUR), Japanese Yen (JPY), New Zealand Dollar (NZD), Norwegian Krone (NOK), Swedish Krona (SEK), Swiss Franc (CHF), British Pound (GBP) and United States Dollar (USD). Each row represents a regression estimation using the column (1) currency as the home currency and the other 9 currencies as foreign currency j. $s_{j,t}$ is the nominal exchange rate between home and foreign country j, defined as home currency price of foreign currency, $q_{j,t}$ is the real exchange rate. $\lambda^{IV}_{j,t}$ is the instrumented measure of government bond liquidity, $i^R_{j,t}$ is the home minus foreign interest rates.

Δ is a difference operator. The instruments for government bond liquidity are change and the level of log of general government debt to GDP for home country and each foreign country j, log of the VIX index, log of the gold price, G10 cross-country average square inflation rates, G10 cross-country average unemployment rates, G10 cross-country average square of change in bilateral exchange rates and G10 cross-country average absolute change of bilateral exchange rates.. The sample period is 1999M1-2017M12. Germany government interest rate and debt to GDP are used for EUR case.
Standard errors in parentheses are standard errors adjusted for cross-sectional correlation. *, **, and *** indicate that the alternative model significantly different from zero at 10%, 5%, and 1% significance level, respectively, based on standard normal critical values for the two-sided test. *, **, and *** for $q_{j,t}$ is based on critical values from distribution for Augmented Dickey Fuller test with a constant.
The table only reports the coefficient estimates of interest. A table that reports all coefficient estimates is available in the supplementary appendix.

Table 4C:
IV Estimation result of

$$\Delta s_{j,t} = \alpha_j + \beta_1 q_{j,t-1} + \beta_2 \Delta\lambda_{j,t}^{IV} + \beta_3 \Delta\tau_{j,t} + \beta_4 \Delta l_{j,t}^{R} + \beta_5 \Delta i_{j,t}^{R} + \beta_6 \lambda_{j,t-1}^{IV} + \beta_7 \tau_{j,t-1} + \beta_8 l_{j,t-1}^{R} + \beta_9 i_{j,t-1}^{R} + u_{j,t}$$

Home Currency (1)	$q_{j,t-1}$ (2)	$\Delta\lambda_{j,t}^{IV}$ (3)	$\Delta i_{j,t}^{R}$ (4)	Observations (5)
AUD	-0.0483***	-13.3167***	-8.4066***	919
	(0.0170)	(4.1661)	(1.1406)	
CAD	-0.0233	-20.8018**	-11.6756***	363
	(0.0165)	(9.1085)	(2.4103)	
EUR	-0.0513***	-10.7230**	-9.3994***	930
	(0.0120)	(4.3001)	(1.5282)	
JPY	-0.0685***	-10.0351**	-11.8043***	930
	(0.0181)	(4.1793)	(1.3937)	
NZD	-0.0431***	-8.0727***	-8.2882***	907
	(0.0146)	(3.0272)	(1.0831)	
NOK	-0.0453***	-4.4598***	-7.2484***	930
	(0.0115)	(1.3558)	(0.9580)	
SEK	-0.0455***	-10.5546***	-7.7481***	930
	(0.0121)	(3.4225)	(1.3410)	
CHF	-0.0260*	13.1020**	4.4559**	852
	(0.0134)	(5.2932)	(2.0139)	
GBP	-0.0441***	-12.7855***	-12.2036***	930
	(0.0157)	(4.2513)	(2.0675)	
USD	-0.0585***	-18.3097***	-12.4256***	777
	(0.0155)	(3.4373)	(1.2397)	

The table reports the OLS estimates of the coefficient of the panel fixed effect regression listed above. The 10 currencies used are Australian Dollar (AUD), Canadian Dollar (CAD), Euro (EUR), Japanese Yen (JPY), New Zealand Dollar (NZD), Norwegian Krone (NOK), Swedish Krona (SEK), Swiss Franc (CHF), British Pound (GBP) and United States Dollar (USD). Each row represents a regression estimation using the column (1) currency as the home currency and the other 9 currencies as foreign currency j. $s_{j,t}$ is the nominal exchange rate between home and foreign country j, defined as home currency price of foreign currency, $q_{j,t}$ is the real exchange rate. $\lambda_{j,t}^{IV}$ is the instrumented measure of government bond liquidity, $i_{j,t}^{R}$ is the home minus foreign interest rates.

Δ is a difference operator. The instruments for government bond liquidity are change and the level of log of general government debt to GDP for home country and each foreign country j, log of the VIX index, log of the gold price, G10 cross-country average square inflation rates, G10 cross-country average unemployment rates, G10 cross-country average square of change in bilateral exchange rates and G10 cross-country average absolute change of bilateral exchange rates.. The sample period is 2008M1-2017M12. Germany government interest rate and debt to GDP are used for EUR case.
Standard errors in parentheses are standard errors adjusted for cross-sectional correlation. *, **, and *** indicate that the alternative model significantly different from zero at 10%, 5%, and 1% significance level, respectively, based on standard normal critical values for the two-sided test. *, **, and *** for $q_{j,t}$ is based on critical values from distribution for Augmented Dickey Fuller test with a constant.
The table only reports the coefficient estimates of interest. A table that reports all coefficient estimates is available in the supplementary appendix.

Table 5A:
Estimation result of

$$\Delta s_{j,t} = \alpha_j + \beta_1 q_{j,t-1} + \beta_2 \Delta \tau_{j,t} + \beta_3 \Delta \gamma_t + \beta_4 \Delta \gamma^*_{j,t} + \beta_5 \Delta i^R_{j,t} + \beta_6 \tau_{t-1} + \beta_7 \gamma_{t-1} + \beta_8 \gamma^*_{j,t-1} + \beta_9 i^R_{j,t-1} + u_{j,t}$$

Home Currency (1)	$\Delta\gamma^*_{j,t}$ (2)	$\Delta\gamma_{j,t}$ (3)	$\Delta\tau_{j,t}$ (4)	Within R^2 (5)	Observations (5)
AUD	5.4814***	-6.7622***	-2.7406**	0.2016	2028
	(0.6856)	(1.2114)	(1.2096)		
CAD	4.4218***	-5.9115***	-5.2253***	0.2078	1836
	(0.6851)	(1.9789)	(1.1260)		
EUR	4.5771***	-4.9551***	-5.0824***	0.1472	2028
	(0.5595)	(1.0948)	(0.9051)		
JPY	4.2658***	-2.0942	-4.8186***	0.1737	2028
	(0.9865)	(5.1736)	(1.5829)		
NZD	6.1084***	-6.7754***	-5.5521***	0.2082	2028
	(0.8609)	(0.8970)	(1.2860)		
NOK	5.5907***	-3.3078***	-5.0194***	0.1640	2028
	(0.7336)	(0.7600)	(1.0395)		
SEK	4.7890***	-4.0441***	-5.0347***	0.1342	2028
	(0.6331)	(1.2212)	(0.9868)		
CHF	3.0852***	-2.7329	-1.2225	0.0562	2028
	(0.7469)	(1.8882)	(1.1921)		
GBP	4.7472***	-3.6829***	-1.1670	0.1385	2028
	(0.7047)	(1.0823)	(1.1121)		
USD	6.2173***	-5.8436***	-6.4704***	0.1875	2028
	(0.8044)	(1.3712)	(1.2023)		

The table reports the OLS estimates of the coefficient of the panel fixed effect regression listed above. The 10 currencies used are Australian Dollar (AUD), Canadian Dollar (CAD), Euro (EUR), Japanese Yen (JPY), New Zealand Dollar (NZD), Norwegian Krone (NOK), Swedish Krona (SEK), Swiss Franc (CHF), British Pound (GBP) and United States Dollar (USD). Each row represents a regression estimation using the column (1) currency as the home currency and the other 9 currencies as foreign currency j. $s_{j,t}$ is the nominal exchange rate between home and foreign country j, defined as home currency price of foreign currency, $q_{j,t}$ is the real exchange rate. $\tau_{j,t}$ is the measure of currency derivative friction, $\hat{\gamma}^*_{j,t}$ is the measure of foreign government bond liquidity, $\hat{\gamma}_{j,t}$ is the measure of the home government bond liquidity, $i^R_{j,t}$ is the home minus foreign interest rates. $\Delta$is a difference operator. The sample period is 1999M1-2017M12. Germany government interest rate is used for EUR case.
Standard errors in parentheses are standard errors adjusted for cross-sectional correlation. *, **, and *** indicate that the alternative model significantly different from zero at 10%, 5%, and 1% significance level, respectively, based on standard normal critical values for the two-sided test.
The table only reports the coefficient estimates of interest. A table that reports all coefficient estimates is available in the supplementary appendix.

Table 5B:
Summary of country by country estimation of
$\Delta s_t = \alpha + \beta_1 q_{t-1} + \beta_2 \Delta\eta_t + \beta_3 \Delta i_t^R + \beta_4 \eta_{t-1} + \beta_5 i_{t-1}^R + u_t$

	q_{t-1} (1)	$\Delta\eta_t$ (2)	Δi_t^R (3)	Adjusted R^2 (4)
	Whole sample: 1999M1-2017M12			
Max	-0.003	1.714	0.250	0.334
Min	-0.116	-9.985	-9.208	0.003
Median	-0.031	-4.160	-5.151	0.170
Mean	-0.038	-4.398	-4.956	0.160
Pairs that are negatively significant at:				
10%	29	37	42	
5%	25	33	42	
1%	13	29	42	
	2008M1-2017M12			
Max	-0.011	2.905	0.767	0.487
Min	-0.198	-11.860	-14.336	0.012
Median	-0.069	-5.251	-6.993	0.281
Mean	-0.070	-5.393	-7.616	0.267
Pairs that are negatively significant at:				
10%	31	38	41	
5%	25	36	40	
1%	11	26	39	

Total number of country pair is 45 (9*10/2). $s_{j,t}$ is the nominal exchange rate between home and foreign country j, defined as home currency price of foreign currency, $q_{j,t}$ is the real exchange rate. η is the measure of government bond liquidity, $i_{j,t}^R$ is the home minus foreign interest rates. Δ is a difference operator. A table that reports all coefficient estimates is available in the supplementary appendix.

Table 6: Out-of-sample fit comparison of different models
Model (20): Rolling window prediction error of regression with liquidity return:
$$\Delta\hat{s}_{j,t} = \hat{\alpha}_j + \hat{\beta}_1 q_{j,t-1} + \hat{\beta}_2 \Delta\eta_{j,t} + \hat{\beta}_3 \Delta i^R_{j,t} + \hat{\beta}_4 \eta_{j,t-1} + \hat{\beta}_5 i^R_{j,t-1}$$
Model (21): Rolling window prediction error of regression without liquidity return:
$$\Delta\hat{s}_{j,t} = \hat{\alpha}_j + \hat{\beta}_1 q_{j,t-1} + \hat{\beta}_2 \Delta i^R_{j,t} + \hat{\beta}_3 i^R_{j,t-1}$$
and random walk (RW) model: $\Delta\hat{s}^{RW}_{j,t} = 0$

Home Currency (1)	RMSE of RW (2)	RMSE of model (21) (3)	RMSE of model (20) (4)	DMW statistics of (21) vs RW (5)	DMW statistics of (20) vs RW (6)	DMW statistics of (20) vs (21) (7)
AUD	0.0333	0.0311	0.0295	5.144	4.953	3.029
CAD	0.0305	0.0281	0.0268	6.291	6.090	4.203
EUR	0.0285	0.0269	0.0259	5.137	4.106	4.126
JPY	0.0428	0.0404	0.0395	5.888	4.868	3.183
NZD	0.0311	0.0298	0.0282	4.502	3.956	3.015
NOK	0.0363	0.0349	0.0316	5.837	3.739	5.493
SEK	0.0296	0.0287	0.0276	3.992	2.616	3.700
CHF	0.0328	0.0333	0.0332	-0.748	-1.368	0.480
GBP	0.0332	0.0317	0.0313	4.241	3.991	1.341
USD	0.0349	0.0336	0.0312	7.068	4.217	5.834

Home Currency	CW statistics of (21) vs RW (8)	p-value of CW test (21) vs RW (9)	CW statistics of (20) vs RW (10)	p-value of CW test (20) vs RW (12)	CW statistics of (20) vs (21) (13)	p-value of CW test (20) vs (21) (14)
AUD	10.270	0.000***	10.064	0.000***	5.357	0.000***
CAD	10.995	0.000***	10.671	0.000***	6.300	0.000***
EUR	7.880	0.000***	9.189	0.000***	6.341	0.000***
JPY	9.460	0.000***	10.675	0.000***	6.550	0.000***
NZD	8.170	0.000***	8.016	0.000***	5.051	0.000***
NOK	7.858	0.000***	11.076	0.000***	9.007	0.000***
SEK	6.409	0.000***	8.290	0.000***	6.465	0.000***
CHF	0.809	0.209	2.014	0.022**	2.647	0.004***
GBP	7.299	0.000***	8.305	0.000***	3.829	0.000***
USD	8.585	0.000***	11.873	0.000***	9.371	0.000***

The 10 currencies used are Australian Dollar (AUD), Canadian Dollar (CAD), Euro (EUR), Japanese Yen (JPY), New Zealand Dollar (NZD), Norwegian Krone (NOK), Swedish Krona (SEK), Swiss Franc (CHF), British Pound (GBP) and United States Dollar (USD). Each row represents a rolling window predictive regression using the column (1) currency as the home currency and the other 9 currencies as foreign currency j. $s_{j,t}$ is the nominal exchange rate between home and foreign country j, defined as home currency price of foreign currency, $q_{j,t}$ is the real exchange rate. η is the measure of government bond liquidity, $i^R_{j,t}$ is the home minus foreign interest rates. Δ is a difference operator. The rolling window is 108 months. The first estimated coefficient uses sample from 1999M1 to 2007M12. Germany government interest rate is used for EUR case. DMW stands for Diebold and Mariano (1995) and West (1996) and CW stands for Clark and West (2007)
The null hypotheses are that the models MSE are equal. The alternative hypotheses are that the larger models MSE are smaller than the nested models. *, **, and *** indicate that the alternative model significantly outperforms the smaller nested model at 10%, 5%, and 1% significance level, respectively, based on standard normal critical values for the one-sided test.

Appendix
A1 Derivation of Model of Liquidity Returns

A2 Data Source
includes:
i) generic data source table,
ii) specific data ticker table and
iii) data period table

A3 Summary Statistics

Appendix A1 Derivation of Model of Liquidity Returns

Consider first the problem of the home-country investor. As in Krishnamurthy and Vissing-Jorgensen (2012), Nagel (2016) and Engel (2016), we take a very simple approach to modeling the liquidity service of some assets, by including them in the utility function. In particular, we assume home households maximize:

$$\text{(A.28)}\quad E_0\left\{\sum_{t=0}^{\infty}\beta^t\left[u\left(c_t\right)+v\left(\frac{M_{H,t}}{P_t},\frac{B_{H,t}}{P_t},\frac{S_tB^*_{H,t}}{P_t}\right)\right]\right\}.$$

There are six assets in the world economy:

M_t - home country money

M_t^* - foreign country money

B_t - home country government bonds

B_t^* - foreign country government bonds

B_t^m- home country "market" bonds

B_t^{*m} - foreign country "market" bonds

The H subscript in the asset holdings refers to home country holdings of each asset, while F will denote foreign country holdings. c_t (c_t^*) is home (foreign) country consumption.

The utility function for the home household shows that it may get liquidity services from home money, home government bonds and foreign government bonds. Below we will specify that holdings of each of these assets must be weakly positive. We will assume that the supplies of the assets and the parameterization of the utility function is such that the home household will always hold home money and government bonds and get liquidity services from those assets, but it may hold a zero amount of foreign government bonds in equilibrium. The utility function $v(.)$ is assumed to be strictly concave, but Inada conditions do not hold for the foreign government bond, so its holdings may be zero. An example of such a utility function, which we will use illustratively below is:

$$\text{(A.29)}\quad v\left(\frac{M_{H,t}}{P_t},\frac{B_{H,t}}{P_t},\frac{S_tB^*_{H,t}}{P_t}\right)=\frac{1}{1-\gamma}\left[\left(\frac{M_{H,t}}{P_t}\right)^{\frac{\varepsilon-1}{\varepsilon}}+\left(\frac{\kappa B_{H,t}}{P_t}\right)^{\frac{\varepsilon-1}{\varepsilon}}+\left(\frac{\eta S_tB^*_{H,t}}{P_t}+\mu\right)^{\frac{\varepsilon-1}{\varepsilon}}\right]^{\frac{(1-\gamma)\varepsilon}{\varepsilon-1}}$$

where we assume $\varepsilon>1$, $\gamma>0$, $0<\kappa<1$, $0<\eta<1$, $\mu\geq 0$.

This specification is a slight generalization of that of Nagel (2016) because we assume that there are two non-money assets that might deliver liquidity services. In addition, Nagel assumes that the liquidity from money and domestic government bonds are perfect substitutes (though bonds provide less liquidity per currency unit), while we allow imperfect substitution.

The period-by-period budget constraint is given by

$$\text{(A.30)}\quad \begin{aligned}&P_tc_t+M_{H,t}+B_{H,t}+B^m_{H,t}+S_tB^*_{H,t}+S_tB^{*m}_{H,t}\\&=P_ty_t+M_{H,t-1}+\left(1+i_{t-1}\right)B_{H,t-1}+\left(1+i^m_{t-1}\right)B^m_{H,t-1}+S_t\left(1+i^*_{t-1}\right)B^*_{H,t-1}+S_t\left(1+i^{*m}_{t-1}\right)B^{*m}_{H,t-1}\end{aligned}$$

Households maximize (A.28) subject to (A.30), and to the constraints $M_{H,t}\geq 0$, $B_{H,t}\geq 0$ and $B^*_{H,t}\geq 0$. These latter constraints mean that households are unable to issue securities with the same liquidity properties as government securities.

We will assume, for convenience, that as in the New Keynesian model in the paper, goods prices in each currency are known one period in advance. The first-order conditions are given by:

$$\text{(A.31)}\quad -\frac{1}{P_t}u'(c_t)+\frac{1}{P_{t+1}}\beta E_t u'(c_{t+1})+\frac{1}{P_t}v_M\left(\frac{M_{H,t}}{P_t},\frac{B_{H,t}}{P_t},\frac{S_t B^*_{H,t}}{P_t}\right)\le 0$$

$$\text{(A.32)}\quad -\frac{1}{P_t}u'(c_t)+\frac{1+i_t}{P_{t+1}}\beta E_t u'(c_{t+1})+\frac{1}{P_t}v_B\left(\frac{M_{H,t}}{P_t},\frac{B_{H,t}}{P_t},\frac{S_t B^*_{H,t}}{P_t}\right)\le 0$$

$$\text{(A.33)}\quad -\frac{1}{P_t}u'(c_t)+\frac{1+i_t^m}{P_{t+1}}\beta E_t u'(c_{t+1})=0$$

$$\text{(A.34)}\quad -\frac{S_t}{P_t}u'(c_t)+\frac{1+i_t^*}{P_{t+1}}\beta E_t S_{t+1}u'(c_{t+1})+\frac{S_t}{P_t}v_{B^*}\left(\frac{M_{H,t}}{P_t},\frac{B_{H,t}}{P_t},\frac{S_t B^*_{H,t}}{P_t}\right)\le 0$$

$$\text{(A.35)}\quad -\frac{S_t}{P_t}u'(c_t)+\frac{1+i_t^{*m}}{P_{t+1}}\beta E_t S_{t+1}u'(c_{t+1})=0$$

The foreign household's problem is symmetric. For convenience, we assume they have the same utility function for consumption as home households. The utility function for liquidity is symmetric to the home household's, with foreign assets taking the place of home assets. In the example we will use later:

$$\text{(A.36)}\quad v^*\left(\frac{M^*_{F,t}}{P^*_t},\frac{B^*_{F,t}}{P^*_t},\frac{S_t^{-1}B_{F,t}}{P^*_t}\right)=\frac{1}{1-\gamma}\left[\left(\frac{M^*_{F,t}}{P^*_t}\right)^{\frac{\varepsilon-1}{\varepsilon}}+\left(\frac{\kappa B^*_{F,t}}{P^*_t}\right)^{\frac{\varepsilon-1}{\varepsilon}}+\left(\frac{\eta S_t^{-1}B_{F,t}}{P^*_t}+\mu\right)^{\frac{\varepsilon-1}{\varepsilon}}\right]^{\frac{(1-\gamma)\varepsilon}{\varepsilon-1}}.$$

The first-order conditions for the foreign household are:

$$\text{(A.37)}\quad -\frac{1}{P^*_t}u'(c^*_t)+\frac{1}{P^*_{t+1}}\beta E_t u'(c^*_{t+1})+\frac{1}{P^*_t}v^*_{M^*}\left(\frac{M^*_{F,t}}{P^*_t},\frac{B^*_{F,t}}{P^*_t},\frac{S_t^{-1}B_{F,t}}{P^*_t}\right)\le 0$$

$$\text{(A.38)}\quad -\frac{1}{P^*_t}u'(c^*_t)+\frac{1+i^*_t}{P^*_{t+1}}\beta E_t u'(c^*_{t+1})+\frac{1}{P^*_t}v^*_{B^*}\left(\frac{M^*_{F,t}}{P^*_t},\frac{B^*_{F,t}}{P^*_t},\frac{S_t^{-1}B_{F,t}}{P^*_t}\right)\le 0$$

(A.39) $-\frac{1}{P_t^*}u'\left(c_t^*\right)+\frac{1+i_t^{*m}}{P_{t+1}^*}\beta E_t u'\left(c_{t+1}^*\right)=0$

(A.40) $-\frac{S_t^{-1}}{P_t^*}u'\left(c_t^*\right)+\frac{1+i_t}{P_{t+1}^*}\beta E_t S_{t+1}^{-1}u'\left(c_{t+1}^*\right)+\frac{S_t^{-1}}{P_t^*}v_B^*\left(\frac{M_{F,t}^*}{P_t^*},\frac{B_{F,t}^*}{P_t^*},\frac{S_t^{-1}B_{F,t}}{P_t^*}\right)\leq 0$

(A.41) $-\frac{S_t^{-1}}{P_t^*}u'\left(c_t^*\right)+\frac{1+i_t^m}{P_{t+1}^*}\beta E_t S_{t+1}^{-1}u'\left(c_{t+1}^*\right)=0$

Equations (A.33) and (A.35) imply the relationship:

$$\left(1+i_t^m\right)E_t u'\left(c_{t+1}\right)=\left(1+i_t^{*m}\right)E_t\frac{S_{t+1}}{S_t}u'\left(c_{t+1}\right)=0.$$

If we maintain the assumption of rational expectations and no market frictions, then the assumption that the conditional distribution of exchange rates and consumption is jointly lognormal, we can derive

$$i_t^{*m}+E_t s_{t+1}-s_t-i_t^m=-\tfrac{1}{2}\operatorname{var}_t\left(s_{t+1}\right)-\operatorname{cov}_t\left(m_{t+1},s_{t+1}\right)$$

where $m_{t+1}=\ln\left(\frac{u'\left(c_{t+1}\right)}{P_{t+1}}\right)$. If markets are complete, we have $s_{t+1}-s_t=m_{t+1}^*-m_{t+1}$, where $m_{t+1}^*=\ln\left(\frac{u'\left(c_{t+1}^*\right)}{P_{t+1}^*}\right)$. Using this relationship, we can write

(A.42) $$i_t^{*m}+E_t s_{t+1}-s_t-i_t^m=r_t$$

where $r_t=\tfrac{1}{2}\left(\operatorname{var}_t\left(m_{t+1}\right)-\operatorname{var}_t\left(m_{t+1}^*\right)\right)$. As noted in the text, we do not insist that r_t be interpreted as a time-varying risk premium. It may arise for other reasons as well, such as financial market or expectational frictions, or from the presence of noise traders. While we derived (A.42) from (A.33) and (A.35), it is straightforward to check that equations (A.39) and (A.41) imply the same relationship.[31]

Assume equations (A.31) and (A.32) hold with equality, so that the home agent holds positive amounts of home money and home government bonds. (A.33) implies:

$$\text{(A.43)} \qquad \frac{1}{P_{t+1}}\beta E_t u'\left(c_{t+1}\right) = \frac{1}{\left(1+i_t^m\right)P_t}u'\left(c_t\right).$$

Substitute this into (A.32), and cancel terms to get:

$$\text{(A.44)} \qquad \frac{1+i_t}{1+i_t^m} + \frac{v_B\left(\frac{M_{H,t}}{P_t}, \frac{B_{H,t}}{P_t}, \frac{S_t B_{H,t}^*}{P_t}\right)}{u'\left(c_t\right)} = 1.$$

Similarly, substituting (A.43) into (A.31) gives us:

$$\frac{1}{1+i_t^m} + \frac{v_M\left(\frac{M_{H,t}}{P_t}, \frac{B_{H,t}}{P_t}, \frac{S_t B_{H,t}^*}{P_t}\right)}{u'\left(c_t\right)} = 1.$$

Rearranging these two equations, we find:

$$\text{(A.45)} \quad i_t^m - i_t = \frac{v_B\left(\frac{M_{H,t}}{P_t}, \frac{B_{H,t}}{P_t}, \frac{S_t B_{H,t}^*}{P_t}\right)}{v_M\left(\frac{M_{H,t}}{P_t}, \frac{B_{H,t}}{P_t}, \frac{S_t B_{H,t}^*}{P_t}\right) - v_B\left(\frac{M_{H,t}}{P_t}, \frac{B_{H,t}}{P_t}, \frac{S_t B_{H,t}^*}{P_t}\right)} i_t.$$

The model in the text approximates this equation around a steady state in which $i_t \approx 0$, to arrive at

[31] These relationships are well-known in the literature. See the survey of Engel (2014) for example.

$$i_t^m - i_t = \alpha i_t$$

We will have $\alpha > 0$ if $v_M > v_B$ in the steady state, so the liquidity value of money exceeds that of home government bonds. Taking the analogous set of relationships for the foreign country, and assuming $\alpha = \frac{\bar{v}_B}{\bar{v}_M - \bar{v}_B} = \frac{\bar{v}^*_{B^*}}{\bar{v}^*_{M^*} - \bar{v}^*_{B^*}}$ (the overbar indicates the functions are evaluated at the steady state levels of the assets) we find:

$$\left(i_t^m - i_t\right) - \left(i_t^{m*} - i_t^*\right) = \alpha\left(i_t - i_t^*\right).$$

If we had added a shock to liquidity preferences as in Engel (2016), we would then, using (A.42) arrive exactly at the model given in the text, in which

$$i_t^* + E_t s_{t+1} - s_t - i_t = \eta_t + r_t,$$

where $\eta_t \equiv \left(i_t^m - i_t\right) - \left(i_t^{m*} - i_t^*\right) = \alpha\left(i_t - i_t^*\right) + v_t$.

Note that if the home household holds the foreign government bond, we have:

$$\frac{1+i_t^*}{1+i_t^m} E_t\left(\frac{S_{t+1}}{S_t}\right) + \frac{v_{B^*}\left(\frac{M_{H,t}}{P_t}, \frac{B_{H,t}}{P_t}, \frac{S_t B^*_{H,t}}{P_t}\right)}{u'\left(c_t\right)} = 1.$$

Together with equation (A.44), we find:

$$\left(1+i_t^*\right) E_t\left(\frac{S_{t+1}}{S_t}\right) - \left(1+i_t\right) = \left(1+i_t^m\right) \frac{v_B\left(\frac{M_{H,t}}{P_t}, \frac{B_{H,t}}{P_t}, \frac{S_t B^*_{H,t}}{P_t}\right) - v_{B^*}\left(\frac{M_{H,t}}{P_t}, \frac{B_{H,t}}{P_t}, \frac{S_t B^*_{H,t}}{P_t}\right)}{u'\left(c_t\right)}$$

Our model implies that if home households hold both government bonds, the difference in the expected rates of return reflects the difference in the liquidity services that the two bonds provide to home households. If the foreign government bond pays a higher monetary return, it must provide a lower liquidity return to the home household in equilibrium.

For the utility function given in (A.29), we can derive that the liquidity premium from the right-hand-side of equation (A.45) is given by:

$$\frac{v_B\left(\frac{M_{H,t}}{P_t},\frac{B_{H,t}}{P_t},\frac{S_tB^*_{H,t}}{P_t}\right)}{v_M\left(\frac{M_{H,t}}{P_t},\frac{B_{H,t}}{P_t},\frac{S_tB^*_{H,t}}{P_t}\right)-v_B\left(\frac{M_{H,t}}{P_t},\frac{B_{H,t}}{P_t},\frac{S_tB^*_{H,t}}{P_t}\right)}i_t=\frac{\left(M_{H,t}\right)^{\frac{1}{\varepsilon}}\kappa^{\frac{\varepsilon-1}{\varepsilon}}}{\left(B_{H,t}\right)^{\frac{1}{\varepsilon}}-\left(M_{H,t}\right)^{\frac{1}{\varepsilon}}\kappa^{\frac{\varepsilon-1}{\varepsilon}}}i_t\ .$$

As $\varepsilon\rightarrow\infty$, so the liquidity services provided by government bonds are simply a diminished service identical to that provided by money, the liquidity return goes to $\frac{\kappa}{1-\kappa}i_t$.

Appendix A2: Data source

Generic data source table

Data	Data source
Spot Exchange rates	Datastream (DS)
1Y Forward rates	Datastream (DS)
1M Forward rates	Datastream (DS)
1Y Government bond yield	Datastream (DS), Bloomberg (BBG), central banks
1M Government bond yield	Datastream (DS), Bloomberg (BBG), central banks
1Y Interest Rate Swap	Bloomberg (BBG)
1Y Credit Default Swap	Bloomberg (BBG), Markit (MK)
Consumer Price Index	IMF IFS
Unemployment rates	IMF IFS, FRED for New Zealand
Gold price	FRED
VIX index	FRED
General Govt Debt to GDP	BIS Credit to the non-financial sector dataset

Specific data ticker table

All the variables are created by filling the missing value in the order reported. For exchange rates and forward rates, we do a trilateral cross to get the non-US related exchange rates. For example, the AUD per CAD exchange rate is constructed by log($S_{USD/CAD}$)- log($S_{USD/AUD}$). Germany government yield, debt to GDP and CDS are used for EUR.

Data	AUD	CAD	EUR	JPY	NZD	NOK	SEK	CHF	GBP	USD
Spot exchange rates	AUSTDO$	CNDOLL$	USEURSP	JAPAYE$	NZDOLL$	NORKRO$	SWEKRO$	SWISSF$	USDOLLR	-
1Y forward rates	USAUDYF	USCADYF	USEURYF	USJPYYF	USNZDYF	USNOKYF	USSEKYF	USCHFYF	USGBPYF	-
1M forward rates	USAUD1F	USCAD1F	USEUR1F	USJPY1F	USNZD1F	-	USSEK1F	USCHF1F	USGBP1F	-
1Y government bond yield	BBG:GTAUD1Y Govt BBG: C1271Y INDEX	DS:CNTBB1Y BBG: C1011Y INDEX	BBG:GTDEM1Y Govt BBG: C9101Y INDEX	BBG:GTJPY1Y Govt BBG: C1051Y INDEX	BBG:GTNZD1Y Govt DS:NZGBY1Y BBG: C2501Y INDEX	BBG:ST3XY Index BBG: C2661Y INDEX	Sveriges Riksbank website, Treasury bills SE12M BBG:BV010259 Index BBG: C2591Y INDEX	Swiss National Bank, spot interest rate for 1Y govt bond BBG: C2561Y INDEX	BBG:GTGBP1Y Govt	BBG:GB12 Govt FRED BBG: C0821Y INDEX
1M government bond yield	DS:TRAU1MT BBG: AUTE1MYL Index	DS:TRCN1MT BBG: FMSTTB1M Index	DS:TRBD1MT BBG: GETB1M Index	DS:TRJP1MT	DS:TRNZ1MT BBG: NDTB1M Curncy		DS:TRSD1MT	DS:TRSW1MT	DS:TRUK1MT BBG: UKGTB1M Index	DS:TRUS1MT BBG: GB1M Index
1Y Interest Rate Swap*	BBG:ADSWAP1Q CURNCY BBG:ADSWAP1 CURNCY	BBG:CDSW1 CURNCY	BBG:EUSW1V3 CURNCY BBG:EUSA1 CURNCY	BBG:JYSW1 CURNCY	BBG:NDSWAP1 CURNCY	BBG:NKSW1 CURNCY	BBG:SKSW1 CURNCY	BBG:SFSW1V3 CURNCY BBG:SFSW1 CURNCY	BBG:BPSW1V3 CURNCY BBG:BPSW1 CURNCY	BBG:USSW1 CURNCY
1Y Credit Default Swap	BBG:AUSTLA CDS USD SR 1Y D14 Corp MK:QS973P	BBG:CANPAC CDS USD SR 1Y D14 Corp MK:27CBJG	BBG:GERMAN CDS USD SR 1Y D14 Corp MK:3AB549	BBG:JGB CDS USD SR 1Y D14 Corp MK:4B818G	BBG:NZ CDS USD SR 1Y D14 Corp MK:6B5178	BBG:NORWAY CDS USD SR 1Y D14 Corp MK:6CFB55	BBG:SWED CDS USD SR 1Y D14 Corp MK:8F7220	BBG:SWISS CDS USD SR 1Y D14 Corp MK:HPBCIO	BBG:UK CDS USD SR 1Y D14 Corp MK:9A17DE	BBG:US CDS USD SR 1Y D14 Corp MK:9A3AAA
General govt debt to GDP	Q:AU:G:A:N:770:A	Q:CA:G:A:N:770:A	Q:DE:G:A:N:770:A	Q:JP:G:A:N:770:A	Q:NZ:G:A:N:770:A	Q:NO:G:A:N:770:A	Q:SE:G:A:N:770:A	Q:CH:G:A:N:770:A	Q:GB:G:A:N:770:A	Q:US:G:A:N:770:A

*See the data appendix of Du, et al 2018a for the detail of the construction, available at: https://sites.google.com/site/wenxindu/data/govt-cip?authuser=0

Data period

Data	**AUD**	**CAD**	**EUR**	**JPY**	**NZD**	**NOK**	**SEK**	**CHF**	**GBP**	**USD**
Spot exchange rates	99M1-17M12	99M1-17M12	99M1-17M12	99M1-17M12	99M1-17M12	99M1-17M12	99M1-17M12	99M1-17M12	99M1-17M12	99M1-17M12
1Y forward rates	99M1-17M12	99M1-17M12	99M1-17M12	99M1-17M12	99M1-17M12	99M1-17M12	99M1-17M12	99M1-17M12	99M1-17M12	99M1-17M12
1M forward rates	99M1-17M12	99M1-17M12	99M1-17M12	99M1-17M12	99M1-17M12	99M1-17M12	99M1-17M12	99M1-17M12	99M1-17M12	99M1-17M12
1Y government bond yield	99M11-17M12	99M1-17M12	99M11-17M12	99M11-17M12	99M1-17M12	99M1-17M12	99M1-17M12	99M1-17M12	99M11-17M12	99M1-17M12
1M government bond yield	99M1-00M6, 00M9, 00M12, 01M3, 09M11-13M3	99M1-17M12	10M11-17M12	12M8-17M12	99M1-17M12	NA	99M1-17M12	09M1-17M12	99M1-17M12	99M1-17M12
1Y Interest Rate Swap	99M1-17M12	01M2-17M12	99M1-17M12	99M1-17M12	99M1-17M12	99M1-17M12	99M1-17M12	99M1-17M12	99M1-17M12	99M1-17M12
1Y Credit Default Swap	08M3-17M12	09M4-17M12*	08M1-17M12	08M1-17M12	08M2-17M12**	08M1-17M12	08M1-17M12	09M1-17M12	08M1-17M12	08M1-17M12
Consumer Price Index	99Q1-17Q4	99M1-17M12	99M1-17M12	99M1-17M12	99Q1-17Q4	99M1-17M12	99M1-17M12	99M1-17M12	99M1-17M12	99M1-17M12
Unemployment rates	99M1-17M12	99M1-17M12	99M1-17M12	99M1-17M12	99Q1-17Q4	99M1-17M12	99M1-17M12	99M1-17M12	99M1-17M12	99M1-17M12
Gold price	NA	NA	NA	NA	NA	NA	NA	NA	NA	99M1-17M12
VIX	NA	NA	NA	NA	NA	NA	NA	NA	NA	99M1-17M12
General govt debt to GDP	99Q1-17Q4	99Q1-17Q4	00Q1-17Q4	99Q1-17Q4	99Q1-17Q4	00Q1-17Q4	99Q1-17Q4	99Q1-17Q4	00Q1-17Q4	99Q1-17Q4

*there are multiple missing values in different months
**there are missing values at 2008m3-m4

Appendix A3: Summary statistics

All the summary statistics scaled by 100 to improve visibility. For example, *i* of 4.06 represents 4.06% annualized interest rate. Interest rates and forward rates reported are with 1-year tenor.

	AUD					CAD				
	Obs	Mean	SD	Min	Max	Obs	Mean	SD	Min	Max
s (ln(S))	2052	-0.7022	1.5554	-4.671	1.091	2052	-0.7807	1.5499	-4.799	0.933
Δs (%)	2052	-0.0657	3.0878	-13.335	25.511	2052	-0.0435	2.9058	-13.775	21.062
q(ln(Q))	2052	-0.7345	1.5707	-4.766	1.018	2052	-0.7791	1.5681	-4.855	0.962
i^R (%)	2052	1.9442	1.5960	-2.489	6.076	2052	0.0470	1.6446	-4.146	5.848
Δi^R (%)	2052	0.0013	0.2357	-1.279	1.408	2052	-0.0003	0.2021	-1.226	1.034
$f - s$ (%)	2052	2.1930	1.7595	-2.474	7.001	2052	-0.0033	1.8152	-5.420	6.112
η (%)	2052	0.2488	0.3070	-0.990	1.605	2052	-0.0502	0.3008	-1.576	1.126
$\Delta \eta$ (%)	2052	0.0008	0.1725	-1.256	1.207	2052	0.0007	0.1432	-1.308	1.156
τ (%)	2029	0.1580	0.2037	-0.381	1.123	1845	0.0770	0.2021	-0.528	1.252
l^R (%)	1121	0.0314	0.1163	-0.264	0.603	530	0.0322	0.1368	-0.474	0.381
λ (%)	1121	0.0853	0.3060	-1.027	1.304	530	-0.0272	0.3185	-1.280	0.642
$\eta - \tau$ (%)	2029	0.0901	0.3009	-1.109	1.303	1845	-0.1169	0.3048	-1.510	0.603
i (%)	2052	4.0617	1.4967	1.502	6.682	2052	2.3542	1.6275	0.409	6.062
IRS (%)	2052	4.4784	1.6936	1.637	7.984	1845	2.2344	1.3400	0.461	5.720
Govt debt to GDP (%)	684	18.9197	9.0569	8.100	37.500	684	64.7149	7.5029	48.800	80.300

	EUR					JPY				
	Obs	Mean	SD	Min	Max	Obs	Mean	SD	Min	Max
s (ln(S))	2052	-1.2008	1.5229	-5.128	0.541	2052	4.1758	0.8535	2.378	5.513
Δs (%)	2052	0.0129	2.5820	-15.628	17.877	2052	0.0272	3.7519	-25.511	14.005
q(ln(Q))	2052	-1.1907	1.5421	-5.165	0.581	2052	4.2362	0.8590	2.338	5.595
i^R (%)	2052	-0.6449	1.5885	-4.241	4.642	2052	-2.4247	1.9632	-6.993	0.973
Δi^R (%)	2052	-0.0020	0.1883	-1.212	1.135	2052	0.0126	0.2052	-1.376	1.279
$f - s$ (%)	2052	-0.7570	1.7470	-4.810	4.826	2052	-2.7403	2.0239	-7.911	1.069
η (%)	2052	-0.1121	0.2893	-1.497	1.071	2052	-0.3157	0.3010	-2.026	0.982
$\Delta \eta$ (%)	2052	0.0001	0.1381	-1.259	1.723	2052	-0.0008	0.1619	-1.353	2.464
τ (%)	2029	-0.1032	0.2149	-1.340	0.451	2029	-0.0890	0.2343	-0.959	0.743
l^R (%)	1177	-0.0400	0.1169	-0.726	0.513	1184	0.0210	0.1191	-0.703	0.512
λ (%)	1177	0.0293	0.3150	-1.444	1.521	1184	-0.1862	0.3071	-1.890	0.658
$\eta - \tau$ (%)	2029	-0.0100	0.3118	-1.310	1.385	2029	-0.2285	0.2853	-1.784	0.539
i (%)	2052	1.7316	1.7475	-0.919	5.043	2052	0.1298	0.2253	-0.328	0.782
IRS (%)	2052	2.0567	1.7446	-0.329	5.381	2052	0.2583	0.2718	-0.140	1.081
Govt debt to GDP (%)	642	68.4822	6.9507	57.200	81.100	684	159.23	31.082	95.700	201.50

	NZD					NOK				
	Obs	Mean	SD	Min	Max	Obs	Mean	SD	Min	Max
s (ln(S))	2052	-0.5271	1.5634	-4.558	1.297	2052	1.1395	1.5287	-3.063	2.639
Δs (%)	2052	-0.0971	3.3520	-14.005	21.551	2052	0.0671	2.8650	-15.512	20.633
q(ln(Q))	2052	-0.5587	1.5787	-4.650	1.238	2052	1.1310	1.5486	-3.156	2.634
i^R (%)	2052	2.2993	1.5487	-2.206	6.957	2052	0.8790	1.8196	-4.090	6.993
Δi^R (%)	2052	0.0012	0.2579	-1.217	1.388	2052	-0.0078	0.2229	-1.408	1.083
$f - s$ (%)	2052	2.6107	1.7379	-2.157	7.911	2052	0.8600	2.0219	-4.660	7.268
η (%)	2052	0.3113	0.3896	-1.379	2.001	2052	-0.0190	0.3524	-2.142	1.513
$\Delta \eta$ (%)	2052	0.0018	0.2379	-1.420	1.366	2052	-0.0017	0.1873	-2.464	0.994
τ (%)	2029	0.1424	0.2328	-0.545	1.365	2029	-0.1095	0.1901	-1.101	0.532
l^R (%)	1073	0.0857	0.1387	-0.248	0.817	1054	-0.0923	0.1333	-0.846	0.126
λ (%)	1073	0.0873	0.3512	-0.909	1.890	1054	0.0169	0.3631	-1.807	1.630
$\eta - \tau$ (%)	2029	0.1691	0.4290	-1.292	1.784	2029	0.0878	0.3519	-1.602	1.752
i (%)	2052	4.3813	1.7397	1.773	7.739	2052	3.1031	2.0423	0.419	7.018
IRS (%)	2052	4.8693	2.0617	1.985	8.853	2052	3.5178	2.1694	0.779	7.695
Govt debt to GDP (%)	684	26.9570	5.7796	15.600	36.800	642	36.2771	7.5183	22.700	51.900

	SEK					CHF				
	Obs	Mean	SD	Min	Max	Obs	Mean	SD	Min	Max
s (ln(S))	2052	1.2677	1.5173	-2.897	2.752	2052	-0.8396	1.5517	-4.879	0.990
Δs (%)	2052	0.0610	2.7145	-9.570	18.786	2052	-0.1483	2.9065	-19.718	11.893
q(ln(Q))	2052	1.2761	1.5349	-2.939	2.817	2052	-0.8329	1.5769	-4.933	1.101
i^R (%)	2052	-0.4376	1.6605	-4.723	4.672	2052	-1.5843	1.5653	-5.656	3.556
Δi^R (%)	2052	-0.0042	0.2018	-1.388	0.978	2052	0.0046	0.1997	-1.372	0.926
$f - s$ (%)	2052	-0.4171	1.8478	-5.328	4.760	2052	-1.9686	1.6655	-6.185	3.662
η (%)	2052	0.0205	0.3461	-1.473	1.576	2052	-0.3843	0.3382	-2.057	0.676
$\Delta \eta$ (%)	2052	0.0010	0.1652	-1.245	1.762	2052	-0.0014	0.1766	-1.244	2.189
τ (%)	2029	-0.0894	0.1750	-1.164	0.636	2029	-0.0589	0.2067	-0.925	0.668
l^R (%)	1129	-0.0195	0.1165	-0.423	0.589	905	-0.0136	0.1262	-0.416	0.846
λ (%)	1129	0.1797	0.3249	-1.515	1.540	905	-0.3814	0.2741	-1.630	0.860
$\eta - \tau$ (%)	2029	0.1099	0.3304	-1.370	1.379	2029	-0.3284	0.2796	-1.752	0.479
i (%)	2052	1.9181	1.7212	-0.909	4.684	2052	0.8861	1.2324	-0.984	3.827
IRS (%)	2052	2.3506	1.7635	-0.560	5.458	2052	0.9260	1.3310	-1.055	4.030
Govt debt to GDP (%)	642	44.7232	6.8896	35.000	65.733	684	37.5618	7.4843	29.000	48.733

	GBP					USD				
	Obs	Mean	SD	Min	Max	Obs	Mean	SD	Min	Max
s (ln(S))	2052	-1.5305	1.4984	-5.513	-0.034	2052	-1.0022	1.5424	-4.897	0.731
Δs (%)	2052	0.1283	2.9243	-14.482	19.718	2052	0.0580	3.1381	-17.865	13.209
q(ln(Q))	2052	-1.5332	1.5196	-5.595	-0.028	2052	-1.0142	1.5623	-5.114	0.761
i^R (%)	2052	0.3190	1.7716	-4.241	6.068	2052	-0.3970	1.8370	-5.299	5.930
Δi^R (%)	2052	-0.0081	0.2145	-1.286	1.187	2052	0.0027	0.2067	-1.228	1.217
$f - s$ (%)	2052	0.4246	1.9223	-4.440	6.384	2052	-0.2021	2.0335	-6.144	7.129
η (%)	2052	0.1057	0.3061	-1.091	1.619	2052	0.1949	0.3381	-1.161	2.142
$\Delta \eta$ (%)	2052	0.0006	0.1769	-1.366	2.123	2052	-0.0011	0.1670	-1.336	1.409
τ (%)	2029	-0.0312	0.1957	-1.365	0.988	2029	0.1109	0.1845	-0.387	1.217
l^R (%)	995	0.0305	0.1315	-0.461	0.663	940	-0.0221	0.1480	-0.641	0.423
λ (%)	995	0.1345	0.3218	-0.728	1.807	940	0.0018	0.3078	-1.428	1.478
$\eta - \tau$ (%)	2029	0.1362	0.3043	-1.052	1.602	2029	0.0801	0.3160	-1.282	1.486
i (%)	2052	2.5990	2.1680	-0.003	6.195	2052	1.9546	1.9134	0.086	6.057
IRS (%)	2052	3.0572	2.2969	0.310	6.830	2052	2.3655	2.1001	0.261	7.500
Govt debt to GDP (%)	642	59.1850	22.260	33.700	87.900	684	72.226	19.277	46.900	98.700