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LIQUIDITY AND EXCHANGE RATES - AN EMPIRICAL INVESTIGATION

Abstract

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Liquidity and Exchange Rates:

An Empirical Investigation

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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.

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 indeed 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

[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.

[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] 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.

Our study is contemporaneous with Jiang, et al. (2018), but with the following differences: Our empirical specification is derived from a theoretical general equilibrium model.[5] 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. 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 model.[6] 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.[7]

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[4] Namely, Australia, Canada, Germany, Japan, New Zealand, Norway, Sweden, Switzerland, the United Kingdom and the United States.

[5] 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.

[6] 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

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

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 Treasury 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 Treasury bond is more liquid. Investors are willing to hold the government bond instead of the market instrument, because the Treasury 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, up to a constant foreign exchange risk premium (which we normalize to zero), uncovered interest parity holds for the market instruments:

(1) $$i_t^{*m} + E_t s_{t+1} - s_t - i_t^m = 0 ,$$

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:

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

That is, the expected excess return on foreign one-period government bonds (relative to home bonds) is determined 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) $$s_t = -E_t \sum_{j=0}^{\infty}\left(i_{t+j} - i_{t+j}^* - \left(\overline{i - i^*}\right)\right) - E_t \sum_{j=0}^{\infty}\left(\eta_{t+j+1} - \overline{\eta}\right) + \lim_{k\to\infty}\left(E_t s_{t+k} - k\left(\overline{s_{+1} - s}\right)\right).$$

The unconditional mean difference in the home and foreign interest rate is denoted $\overline{i - i^*}$, and the mean of the relative liquidity return is $\overline{\eta}$. Here, $\lim_{k\to\infty}\left(E_t s_{t+k} - k\left(\overline{s_{+1} - s}\right)\right)$ 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 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, the exchange rate will contain a unit root unless the interest rate rule targets the nominal exchange rate.[8]

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 is rises relative to the expected infinite sum of expected 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 ismplie 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".[9] 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.[10]

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,

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[8] See Benigno and Benigno (2008).
[9] See, for example, Frenkel (1976).
[10] 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 instrument, 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) $$\eta_t = \alpha\left(i_t - i_t^*\right) + v_t\,, \quad \alpha > 0\,.$$

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. These firms set their price according to $p_t^{r,H} = E_{t-1}\tilde{p}_t^H$, where $p_t^{r,H}$ is 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), and $E_{t-1}\tilde{p}_t^H$ is the expected optimal price for these firms.

The remaining firms do not change their price optimally, but we assume that these firms build in an automatic price adjustment based on the expectation of the optimal inflation. Their expected inflation is then $E_{t-1}\tilde{p}_t^H - \tilde{p}_{t-1}^H$. The expected inflation for firms that adjust their price is given by $E_{t-1}\tilde{p}_t^H - p_{t-1}^H$.[11] 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 at the equilibrium rate.

We have:

(6) $$p_t^H - p_{t-1}^H = \theta\left(E_{t-1}\tilde{p}_t^H - p_{t-1}^H\right) + (1-\theta)\left(E_{t-1}\tilde{p}_t^H - \tilde{p}_{t-1}^H\right).$$ [12]

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

$$p_t^{*H} - p_{t-1}^{*H} = \theta\left(E_{t-1}\tilde{p}_t^{*H} - p_{t-1}^{*H}\right) + (1-\theta)\left(E_{t-1}\tilde{p}_t^{*H} - \tilde{p}_{t-1}^{*H}\right)$$

We do not (need to) specify here the solution for the optimal equilibrium price, but next we use the fact that there is no pricing to market in the equilibrium price in the LCP model – deviations from the law of one price only occur because of misalignments that arise as the exchange rate changes but prices only slowly adjust. We have:

(7) $$p_t^{*H} - p_{t-1}^{*H} = \theta\left(E_{t-1}\tilde{p}_t^H - E_{t-1}s_t - p_{t-1}^{*H}\right) + (1-\theta)\left(E_{t-1}\tilde{p}_t^H - \tilde{p}_{t-1}^H - \left(E_{t-1}s_t - s_{t-1}\right)\right).$$

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

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

The expected change in the pricing to market arises from the adjustments of the fraction θ of firms that set their prices equal to the expected equilibrium price.

[11] Since firms are selected each period randomly to change their price optimally, the price index at time $t-1$ is the same for those that change optimally and those that let their price rise at the expected equilibrium rate, p_{t-1}^H.

[12] See Engel (2018) for a study of the relationship of the price setting behavior in this model compared to the more standard Calvo pricing framework.

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:

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

In this equation, q_t 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.

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:

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

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

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. 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)) 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) $v_t = \rho v_{t-1} + \varepsilon_t$,

where ε_t is mean-zero, i.i.d., and $0 \le \rho < 1$.

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

(15)

$$q_t = -\left(\frac{\sigma(1+\alpha)+\theta-1}{\theta}\right)\left(\pi_t - \pi_t^*\right) - \left(\frac{(1+\alpha)\left(\sigma(1+\alpha)+\theta-1\right)}{\theta\left(\sigma(1+\alpha)-\delta\right)}\right)\left(u_t - u_t^*\right) - \left(\frac{\sigma(1+\alpha)+\theta-1}{\theta\left(\sigma(1+\alpha)-\rho\right)}\right)v_t .$$

The inflation variables at time *t* are predetermined, so (15) 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:

(16)

$$q_t = \left(\frac{\delta\left(\sigma(1+\alpha)+\theta-1\right)}{\theta\left(\sigma(1+\alpha)-\delta\right)}\right)\left(\pi_t - \pi_t^*\right) - \left(\frac{(1+\alpha)\left(\sigma(1+\alpha)+\theta-1\right)}{\theta\left(\sigma(1+\alpha)-\delta\right)}\right)\left(i_t - i_t^*\right) - \left(\frac{\sigma(1+\alpha)+\theta-1}{\theta\left(\sigma(1+\alpha)-\rho\right)}\right)v_t .$$

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

For our empirical analysis, we will derive an expression for $s_t - s_{t-1}$. Note that

(17) $$s_t - s_{t-1} = q_t - q_{t-1} + \pi_t - \pi_t^* .$$

The price adjustment equation (10) gives us:

(18) $$\pi_t - \pi_t^* = \theta q_{t-1} + E_{t-1} s_t - s_{t-1} = \theta q_{t-1} + i_{t-1} - i_{t-1}^* + \eta_{t-1} = \theta q_{t-1} + (1+\alpha)\left(i_{t-1} - i_{t-1}^*\right) + v_{t-1} .$$

The second equality comes from the financial market equilibrium condition, (3), and the third equality is derived from the specification for liquidity returns, (5).

Substituting (16) and (18) into (17) and rearranging, we find:

(19)
$$\begin{aligned} s_t - s_{t-1} = & \left(\frac{(\theta+\delta-1)\sigma(1+\alpha)}{\sigma(1+\alpha)-\delta}\right) q_{t-1} - \left(\frac{(1+\alpha)\left(\sigma(1+\alpha)+\theta-1\right)}{\theta\left(\sigma(1+\alpha)-\delta\right)}\right)\left(i_t - i_t^*\right) - \left(\frac{\sigma(1+\alpha)+\theta-1}{\theta\left(\sigma(1+\alpha)-\rho\right)}\right) v_t \\ & + \left(\frac{(1+\alpha)\left((\theta+\delta)\sigma(1+\alpha)-\delta\right)}{\theta\left(\sigma(1+\alpha)-\delta\right)}\right)\left(i_{t-1} - i_{t-1}^*\right) + \left(\frac{(\theta+\delta)\sigma(1+\alpha)-\delta}{\theta\left(\sigma(1+\alpha)-\delta\right)}\right) v_{t-1} \end{aligned} .$$

Our data directly measures the liquidity return, η_t, rather than the innovation, v_t, so we use equation (5) to replace v_t with $v_t = \eta_t - \alpha\left(i_t - i_t^*\right)$. Also, because the interest rate differential and the liquidity return are strongly serially correlated, we find it informative to specify the empirical relationship in terms of $i_t - i_t^* - \left(i_{t-1} - i_{t-1}^*\right)$ and $i_{t-1} - i_{t-1}^*$, and $\eta_t - \eta_{t-1}$ and η_{t-1}, rather than in terms of $i_t - i_t^*$, $i_{t-1} - i_{t-1}^*$, η_t and η_{t-1}. The solution is much cleaner and easier to inspect if we assume at this point that the serial correlation of the two error terms are equal, so $\delta = \rho$. Making these substitutions, we find:

$$
\begin{aligned}
(20) \qquad s_t - s_{t-1} &= \left(\frac{(\theta+\rho-1)\sigma(1+\alpha)}{\sigma(1+\alpha)-\rho} \right) q_{t-1} - \left(\frac{\sigma(1+\alpha)+\theta-1}{\theta(\sigma(1+\alpha)-\rho)} \right) \left(i_t - i_t^* - (i_{t-1} - i_{t-1}^*) + \eta_t - \eta_{t-1} \right) \\
&+ \left(\frac{(\theta+\rho-1)(\sigma(1+\alpha)+\theta-1)}{\theta(\sigma(1+\alpha)-\rho)} \right) \left(i_{t-1} - i_{t-1}^* + \eta_{t-1} \right)
\end{aligned}
$$

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.

Before turning to the data, we note a few features of our empirical specification based on (20). 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 (20) 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. Finally, we note that (20) was derived under the simplifying assumption that monetary policy shocks and liquidity shocks are equally serially correlated, $\delta = \rho$. Equation (20) implies that the coefficients on the change in the relative interest rates and the change in the relative liquidity yields are the same, but that would not hold in general if $\delta \neq \rho$, so our empirical specification does not constrain those coefficients to be equal.

3. Empirical Investigation of Treasury Liquidity and Exchange Rates

In this section, we present our empirical results. We first describe how we construct the measure of treasury liquidity in 3.1. Subsection 3.2 presents our baseline result that the change in the relative treasury liquidity returns is strongly correlated with exchange rate movements. We show our results are robust to controlling for certain market frictions in subsection 3.3. Finally, in subsection 3.4, we further confirm that country-specific treasury liquidity matters.

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 of Treasury bond. Whenever needed, we denote the variables of a foreign country *j* as $X_{j,t}^*$, for example, $i_{j,t}^*$ for the interest rate of Treasury 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 $i_t^m - i_t^{m*}$ in equation (1) by using the foreign exchange forward minus spot rate spread, $f_{t,t+1} - s_t$:

$$(21) \qquad \hat{\eta}_t \equiv \left(i_t^m - i_t\right) - \left(i_t^{m*} - i_t^*\right) = f_{t,t+1} - s_t + i_t^* - i_t$$

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 $\hat{\eta}_t$. First, as the term $(i_t^m - i_t) - (i_t^{m*} - i_t^*)$ suggests, it is a relative measure of difference between marketable securities and Treasury 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 treasury bond that is constructed by buying the foreign treasury bond, eliminating exchange rate risks by entering a forward contract. Since the home treasury bond and the synthetic home treasury bond pay equivalent pecuniary returns, the difference between the two gives a proxy of the relative difference in liquidity services the home and foreign treasury bond provide.

In the case where the U.S. is assumed to be the home country, Du, et al. (2018a) denotes the $\hat{\eta}_t$ 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. (2018) take the U.S. as the home country, and define $-\hat{\eta}_t$ as a cross-country average over ten large markets relative to the dollar.

We employ the procedure developed by Du, et al. (2018a) to obtain $\hat{\eta}_t$ for any pair of home currency *i* and foreign currency *j* (100 pairs in total) for the G-10 currencies. To give a sense of how this liquidity measure behaves, we plot the liquidity measure against 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 treasury 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 monthly data from January 1999 to December 2017. 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. We provide the data source details in Appendix A2 and summary statistics for the variables we used in Appendix A3. Appendix A4 reports a large number of robustness checks.

3.2 Baseline Results

To investigate the empirical relationship between treasury liquidity and exchange rates for the G10 countries, we estimate the following panel monthly fixed effect regression from equation (20):

(22) $$\Delta s_{j,t} = \alpha_j + \beta_1 q_{j,t-1} + \beta_2(\Delta\hat{\eta}_{j,t}) + \beta_3(\Delta i^R_{j,t}) + \beta_4(\hat{\eta}_{j,t-1}) + \beta_4(i^R_{j,t-1}) + u_{j,t}\,,$$

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 (22).[13] 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.[14]

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 interest rates and exchange rates has not been universally strong in previous studies.[15] 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 -4.77, 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 4.77 percent appreciation from the previous month.

Our main novel results concern the effects of the liquidity yield on exchange rates. The coefficient estimates for $\Delta\hat{\eta}_{j,t+1}$ are all negative and statistically significant at the 1% level, with

[13] To keep the table visibly clear, we only report the main coefficient estimates of interest and refer readers to the appendix for the full regression tables.
[14] See the discussion and robustness below for the choice of one-year tenor.
[15] See Engel (2014) for a recent survey.

a range from -2.46 to -6.64. This indicates a 2.46% 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 treasury liquidity exhibits a very strong relationship with exchange rate movements for all the G-10 countries.

For comparison, we also conduct the regression (22) but excluding the liquidity yield variables. That is:

$$(23) \qquad \Delta s_{j,t} = \alpha_j + \beta_1 q_{j,t-1} + \beta_2 (\Delta i^R_{j,t}) + \beta_3 (i^R_{j,t-1}) + u_{j,t} \, ,$$

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. This indicates including relative treasury liquidity returns brings strong explanatory power to exchange rate determination, in addition to and independent of the traditional factors.

Next, we investigate whether the relationship between treasury liquidity and exchange rates are driven by the Global Financial Crisis or the post-crisis period. In Table 2C, we re-estimate (22) 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. In the pre-crisis data, the p-values for these coefficients are all less than 0.01 except for Japan (where it is still below 0.10) and Switzerland (which is marginally insignificant.) The coefficient estimates in all cases have larger values in absolute term after 2008, ranging from -3.11 to -7.77. 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 Treasury liquidity and exchange rate determination.

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

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 yield to construct the variables. However, the data availability of one-month government yield is rather limited for some of the sample countries. In addition, in section 3.4, 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 tenor 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 (22), using one-month forward rates and one-month government yield data.[16] 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.

This empirical analysis shows a strong relation between the relative treasury liquidity and the exchange rate. In this subsection, we provide evidence of a causal relationship – that a change in the relative treasury liquidity leads to a change in the bilateral exchange rates by instrumenting the treasury liquidity return. We adopt general government debt to GDP for each country as an instrument – it serves as a proxy of the scarcity of the liquid assets available in an economy. 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

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

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 build on Krishnamurthy and Vissing-Jorgensen (2012), Nagel (2016) and Du, et al (2018a) to instrument the variables $\Delta\hat{\eta}_{j,t+1}$ and $\hat{\eta}_{j,t}$ by the change and the level of log of general government debt to GDP for home country *i* and each foreign country *j* and the log of the VIX index.[17] We obtain the general government debt to GDP data from the BIS credit to the non-financial sector dataset. The debt value is nominal value. We conduct quarterly regressions from 1999Q1 to 2017Q4 because the debt to GDP data is only available at quarterly frequency.

In Table 3, we report the regression coefficients of the quarterly instrumental variable regressions. The instrumented change of treasury liquidity has a negative coefficient in 8 out of 10 regressions and significantly negative in 5 of them. Two of the coefficients are positive but the standard error in both cases are large, indicating they are not significantly different from zero. Overall, we find that the instrument 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 treasury liquidity causes exchange rate movements.

3.3 Decomposing the Liquidity Measure

Up to this point, we have maintained the assumption that markets are frictionless, so we have $\hat{\eta}_t = f_{t,t+1} - s_t + i_t^* - i_t$ to serve as a measure of the relative Treasury liquidity η_t. In this subsection, we discuss some frictions that could possibly drive the movement of $\hat{\eta}_t$ other than the liquidity of government bonds. As we have noted, $\hat{\eta}_t$ can be interpreted as the difference of a synthetic home Treasury bond $f_{t,t+1} - s_t + i_t^*$ and a home Treasury bond i_t. There are two possible frictions to consider – sovereign default risk and a currency derivative market friction. These

[17] Our findings of the effects of government liquidity on the exchange rate are essentially unaffected if we drop VIX as an instrument, but the first stage fit for liquidity returns is better if VIX is included.

frictions are important in the recent literature in international finance, and there are readily available prices that can be used to quantify these frictions.[18]

First, investors might not be able to construct the synthetic home Treasury 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. For example, Du, et al. (2018b) argue that in recent years, for some currencies (particularly, when the U.S. dollar is the home currency), we find $IRS_t < f_{t,t+1} - s_t + IRS_t^*$, 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 $\hat{\tau}_t \equiv f_{t,t+1} - s_t + IRS_t^* - IRS_t$ 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, $\hat{\tau}_t$ is high, and the home currency is strong.

Furthermore, even if the currency derivative markets are frictionless, the Treasury bond yields might include expected default risk. If the home Treasury bond is regarded as default-free (say, the U.S. Treasury bond), but the foreign Treasury 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 Treasury bond and home Treasury bond could be different not just because of the difference in Treasury 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 treasury 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

[18] 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.

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 proxy for the expected default loss term, i.e. $\hat{l}_{j,t}^{R} = CDS_t - CDS_{j,t}^{*}$.

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

$$\hat{\eta}_{j,t} = \tau_{j,t} - l_{j,t}^{R} + \lambda_{j,t}, \tag{24}$$

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

We below summarize the components of $\hat{\eta}_{j,t}$ introduced in this subsection:[19]

$$\hat{\tau}_{j,t} = f_{t,t+1} - s_t + IRS_{j,t}^{*} - IRS_t \quad , \quad \hat{l}_{j,t}^{R} = CDS_t - CDS_{j,t}^{*} \quad , \quad \hat{\lambda}_{j,t} = \hat{\eta}_{j,t} - \hat{\tau}_{j,t} + \hat{l}_{j,t}^{R} \tag{25}$$

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,

$$\begin{aligned} \Delta s_{j,t} &= \alpha_j + \beta_1 q_{j,t-1} + \beta_2 \Delta\hat{\lambda}_{j,t} + \beta_3 \Delta\hat{\tau}_{j,t} + \beta_4 \Delta\hat{l}_{j,t}^{R} + \beta_5 \Delta i_{j,t}^{R} \\ &\quad + \beta_6 \hat{\lambda}_{j,t-1} + \beta_7 \hat{\tau}_{j,t-1} + \beta_8 \hat{l}_{j,t-1}^{R} + \beta_9 i_{j,t-1}^{R} + u_{j,t} \end{aligned} \tag{26}$$

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

As discussed above, we expect to find a negative estimate of β_3, because a larger $\Delta\hat{\tau}_{j,t}$ 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 $\Delta\hat{l}_{j,t}^{R}$ means there is a greater default risk for home government bonds. $\Delta\hat{\lambda}_{j,t}$ 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.

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 (26). 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 variables involving CDS data ($\Delta\hat{l}_{j,t+1}^{R}$ and $\hat{l}_{j,t}^{R}$).

In Table 4A, the coefficient estimates on $\Delta\hat{\lambda}_{i,t+1}$, which represents the effect of change of the treasury liquidity after adjusting for credit risk and derivative market friction, are still significantly negative in all cases. The range of coefficient is from -3.22 to -7.08, indicating a monthly 3.22% to 7.08% 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 $\Delta\hat{\eta}_{i,t+1}$ estimated in Table 2A or Table 2C. These results reaffirm our baseline result that there is a strong linkage between treasury liquidity and exchange rate.

In many cases, we also see that credit risk variation and derivative market friction are important variables in explaining the change of exchange rates.[20] The positive coefficient on $\Delta\hat{l}_{j,t+1}^{R}$ indicates that an increase in home default risk relative to foreign default risk is associated with an immediate home currency depreciation. Holding the nominal treasury 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 $\Delta\hat{\tau}_{j,t}$. 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

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

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 $\Delta\hat{\tau}_{j,t}$ 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 contract to hedge exchange rate risk in investing in 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 (26) by including one or two sub-components at a time. The results are reported at Table 4B. Once again, we find the regression coefficients for $\Delta\hat{\lambda}_{j,t+1}$ are significantly negative in all cases.

How much of the variation of $\hat{\eta}_t$ is driven by each of the sub-components? We can answer this with a variance decomposition. Table 4C reports the decomposition given by:

$$(27)\ 1 = \frac{\text{var}(\Delta\hat{\lambda}_t)}{\text{var}(\Delta\hat{\eta}_t)} + \frac{\text{var}(\Delta\hat{\tau}_t)}{\text{var}(\Delta\hat{\eta}_t)} + \frac{\text{var}(\Delta\hat{l}_t^R)}{\text{var}(\Delta\hat{\eta}_t)} + 2\frac{\text{cov}(\Delta\hat{\lambda}_t, \Delta\hat{\tau}_t)}{\text{var}(\Delta\hat{\eta}_t)} - 2\frac{\text{cov}(\Delta\hat{\tau}_t, \Delta\hat{l}_t^R)}{\text{var}(\Delta\hat{\eta}_t)} - 2\frac{\text{cov}(\Delta\hat{l}_t^R, \Delta\hat{\lambda}_t)}{\text{var}(\Delta\hat{\eta}_t)}$$

For most of the countries, the variation of $\Delta\hat{\lambda}_t$ contributes a large share of variation of $\Delta\hat{\eta}_t$. However, the sums of the variance shares of $\Delta\hat{\lambda}_t$, $\Delta\hat{\tau}_t$, and $\Delta\hat{l}_t^R$ are greater than one. This arises because $\Delta\hat{l}_t^R$ is positively correlated with $\Delta\hat{\lambda}_t$ (and $\Delta\hat{l}_t^R$ enters the expression for $\Delta\hat{\eta}_t$ with a negative sign in equation (24)), and because $\Delta\hat{\lambda}_t$ and $\Delta\hat{\tau}_t$ are negatively correlated for most countries. Because all three components contribute to the variation in $\Delta\hat{\eta}_t$, 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.

3.4 Country-specific Treasury Liquidity

So far, we have conducted all our analysis with different measures of the bilateral relative treasury 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 $\hat{\gamma}_t = IRS_t - i_t$ and $\hat{\gamma}^*_{j,t} = IRS^*_t - i^*_t$. Motivated by the decomposition above, we will include also the currency derivative market friction, $\hat{\tau}_{j,t}$. We have then that $\hat{\eta}_{j,t}$ used in our baseline regressions can be decomposed as:

$$(28) \qquad \hat{\eta}_{j,t} = \hat{\tau}_{j,t} + \hat{\gamma}_t - \hat{\gamma}^*_{j,t}$$

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

$$(29) \qquad \Delta s_{j,t} = \alpha_j + \beta_1 q_{j,t-1} + \beta_2 \Delta \hat{\tau}_{j,t} + \beta_3 \Delta \hat{\gamma}_t + \beta_4 \Delta \hat{\gamma}^*_{j,t} + \beta_5 \Delta i^R_{j,t} + \beta_6 \hat{\gamma}_{t-1} + \beta_7 \hat{\gamma}^*_{j,t-1} + \beta_8 i^R_{j,t-1} + u_{j,t}$$

Estimates of β_3 and β_4 in (29) show how the change of country-specific treasury liquidity affects exchange rate movements. We expect a negative sign for β_3 and a positive sign for β_4.

Table 5 presents the estimation results for the country specific treasury liquidity. The second column gives the coefficient estimates for the change in treasury liquidity for all the foreign currencies. The coefficient estimates are all significantly positive, indicating an increase in treasury liquidity of the foreign country is associated with a depreciation of the home currency, which is consistent with our theory.

All the coefficient estimates of the home treasury liquidity, $\Delta \hat{\eta}_t$, term are significantly negative with the exception of the Japanese yen. The home treasury liquidity effect of Japan is negative but not significant and with the smallest absolute size. Over the sample period we considered, Japan has the largest government debt to GDP ratio with a mean of 160%. This might indicate that the liquidity asset supply in Japan is relatively rich, leading to a small liquidity premium and insignificant effect on the exchange rate movements. This is consistent with our instrument strategy in subsection 3.1.

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.

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 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.

References

Avdjiev, Stefan; Wenxin Du; Cathérine Koch; and, Hyun Song Shin. 2018. “The Dollar, Bank Leverage and Deviations from Covered Interest Parity.” **American Economic Review: Insights**, forthcoming.

Benigno, Gianluca; and Pierpaolo Benigno. 2008. "Exchange rate determination under interest rate rules." **Journal of International Money and Finance** 27, 971-993.

Beveridge, Stephen; and Charles R. Nelson. 1981. “A New Approach to Decomposition of Economic Time Series into Permanent and Transitory Components with Particular Attention to Measurement of the ‘Business Cycle.’” **Journal of Monetary Economics** 7, 151–74

Campbell, John Y.; and Richard H. Clarida. 1987. “The Dollar and Real Interest Rates.” **Carnegie-Rochester Conference Series on Public Policy** 27, 103-140.

Della Corte, Pasquale; Lucio Sarno; Maik Schmeling; and Christian Wagner. 2018. “Exchange Rates and Sovereign Risk.” Available at SSRN: https://ssrn.com/abstract=2354935

Du, Wenxin; Joanne Im; and Jesse Schreger. 2018a. “US Treasury Premium.” **Journal of International Economics** 112, 167-181.

Du, Wenxin; Alexander Tepper; and, Adrien Verdelhan. 2018b. “Deviations from Covered Interest Rate Parity.” **Journal of Finance** 73, 915-957.

Dornbusch, Rudiger. 1976. “Expectations and Exchange Rate Dynamics.” **Journal of Political Economy** 84, 1161–76.

Engel, Charles, 2014, “Exchange Rates and Interest Parity.” in Gita Gopinath, Elhanan Helpman and Kenneth Rogoff, eds., **Handbook of International Economics, vol. 4** (Elsevier), 453-522.

Engel, Charles. 2016. “Interest Rates, Exchange Rates and the Risk Premium.” **American Economic Review** 106, 436-474.

Engel, Charles. 2018. “Real exchange rate convergence: The roles of price stickiness and monetary policy.” **Journal of Monetary Economics** Forthcoming.

Eichenbaum, Martin; Benjamin K. Johannsen; and Sergio Rebelo. 2018. “Monetary Policy and the Predictability of Nominal Exchange Rates.” NBER Working Paper No.23158

Frenkel, Jacob A.. 1976. “A monetary approach to the exchange rate: Doctrinal aspects and empirical evidence.” **Scandinavian Journal of Economics** 78, 200-224.

Itskhoki, Oleg; and Dmitry Mukhin. 2017. “Exchange Rate Disconnect in General Equilibrium.” NBER Working Paper No.23401

Jiang, Zhengyang; Arvind Krishnamurthy; and Hanno N Lustig. 2018. “Foreign Safe Asset Demand and the Dollar Exchange Rate.” Stanford University Graduate School of Business Research Paper No. 18-16. SSRN: https://ssrn.com/abstract=3142280

Kollmann, Robert. 2002. “Monetary Policy Rules in the Open Economy: Effects on Welfare and the Business Cycle.” **Journal of Monetary Economics** 49, 989-1015.

Krishnamurthy, Arvind; and Annette Vissing-Jorgensen. 2012. “The Aggregate Demand for Treasury Debt.” **Journal of Political Economy** 120, 233-267.

Linnemann, Ludger, and Andreas Schabert. 2015. “Liquidity Premia and Interest Rate Parity.” **Journal of International Economics** 57, 178-192.

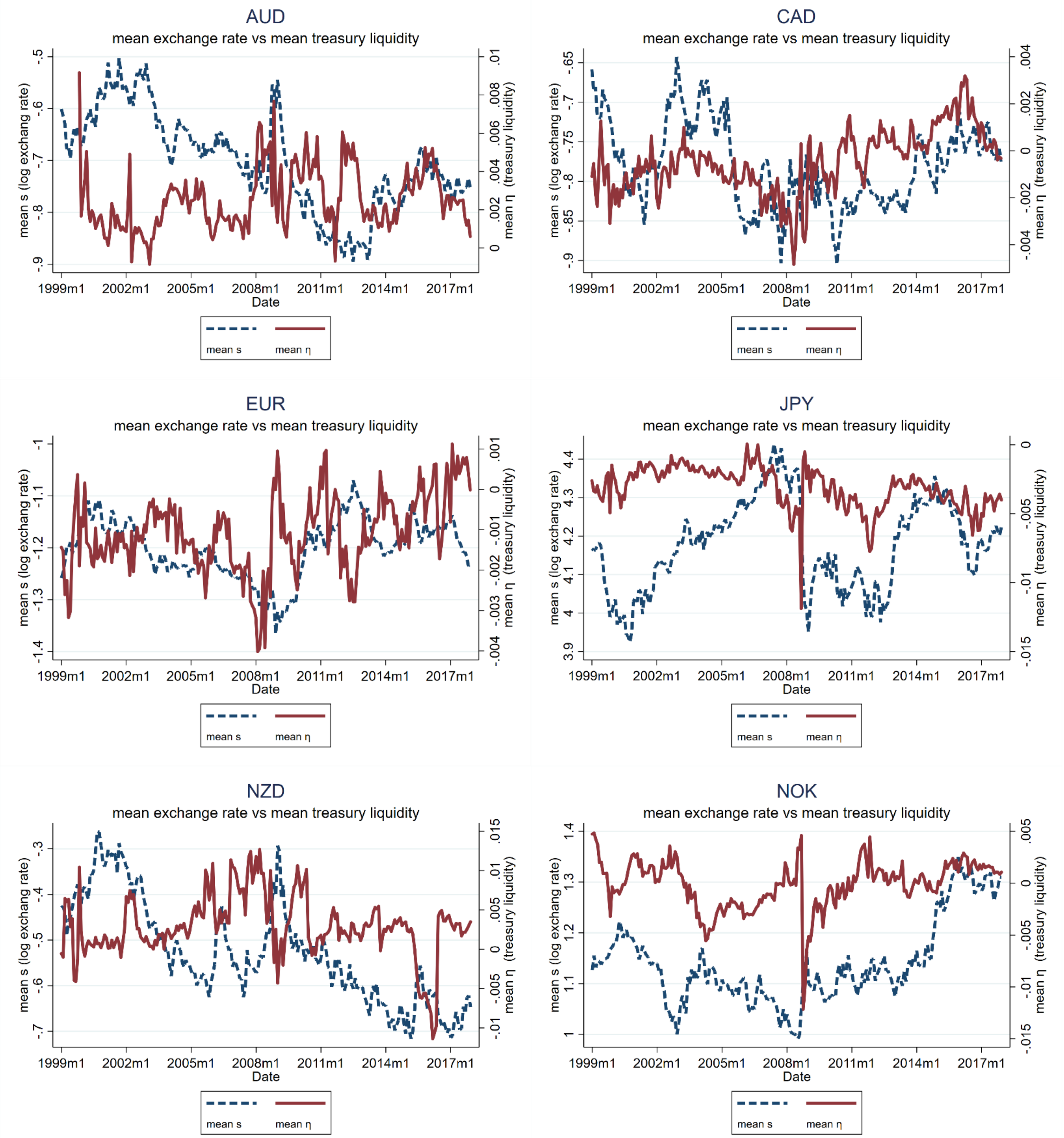
Mark, Nelson. 1995. “Exchange Rates and Fundamentals: Evidence on Long-Run Predictability.” **American Economic Review** 85, 201-218.

Nagel, Stefan. 2016. “The Liquidity Premium of Near-Money Assets.” **Quarterly Journal of Economics** 131, 1927-1971.

Obstfeld, Maurice; and Kenneth Rogoff. 2000. The six major puzzles in international macroeconomics: is there a common cause? **NBER Macroeconomics Annual** 2000, 339–390.

Valchev, Rosen. 2017. “Bond Convenience Yields and Exchange-Rate Dynamics.” Department of Economics, Boston College.

Figure 1:



(Figure 1 continued)

Figure 1 continue

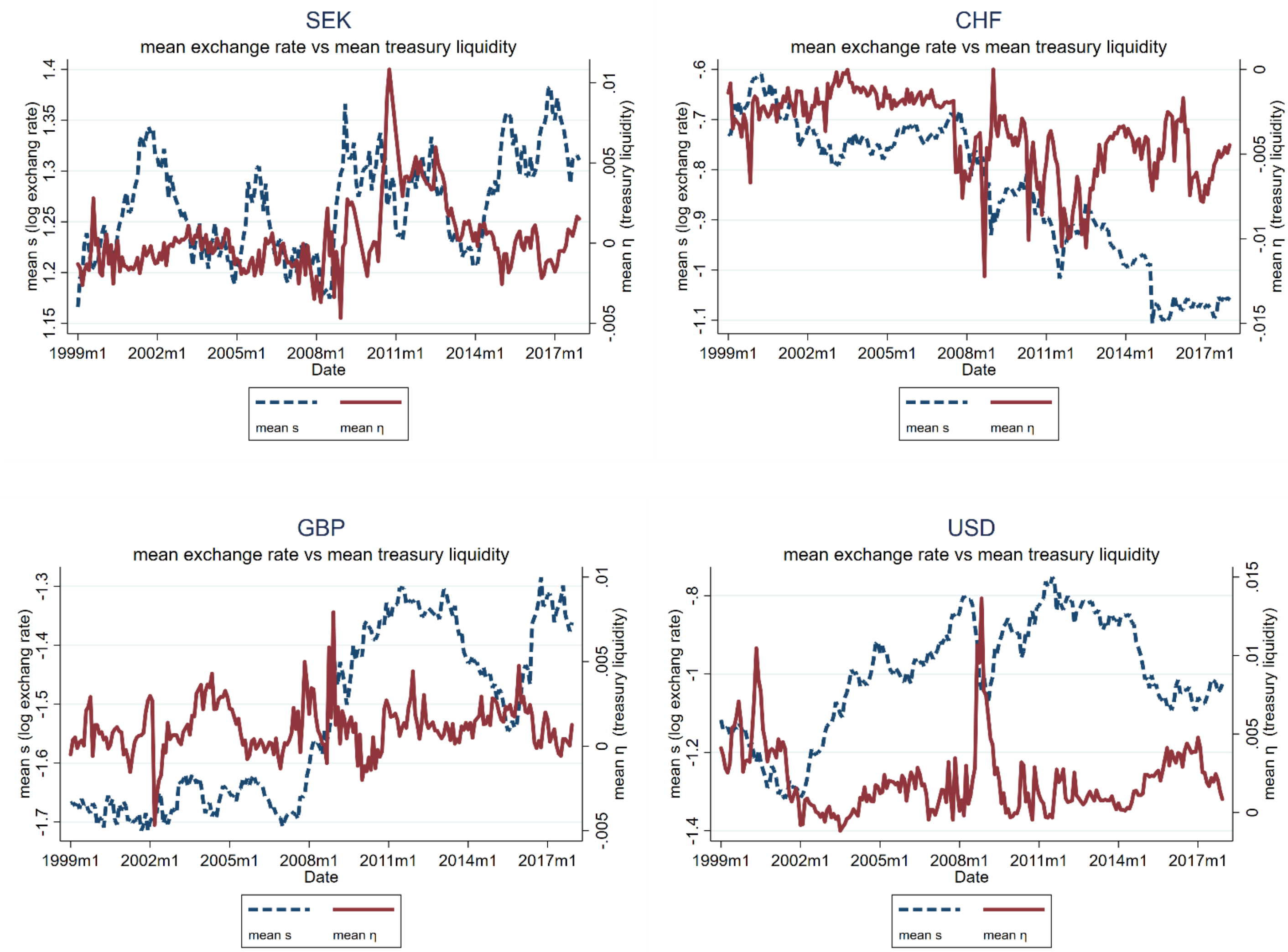


Table 1:

Correlation of $\hat{\eta}_t$ and $i_t - i_t^*$

Home Currency	Correlation of $\hat{\eta}_t$ and $i_t - i_t^*$
AUD	0.4110
CAD	0.4653
EUR	0.4374
JPY	0.1191
NZD	0.2208
NOK	0.4663
SEK	0.4261
CHF	0.1715
GBP	0.3934
USD	0.4937

The 10 currencies used are Australian Dollar (AUD), Canadian Dollar (CAD), Euro (EUR), Japanese Yen (JPY), New Zealand Dollar (NZD), Norwegian Krone (NOK), Swedish Krone (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 $\Delta s_{j,t} = \alpha_j + \beta_1 q_{j,t-1} + \beta_2(\Delta\hat{\eta}_{j,t}) + \beta_3(\Delta i^R_{j,t}) + \beta_4(\hat{\eta}_{j,t-1}) + \beta_4(i^R_{j,t-1}) + u_{j,t}$

Home Currency (1)	$q_{i,t-1}$ (2)	$\Delta\hat{\eta}_{j,t}$ (3)	$\Delta i^R_{j,t}$ (4)	Observations (5)	Within R^2 (6)
AUD	-0.0305***	-5.3390***	-5.9205***	1950	0.2020
	(0.0054)	(0.4364)	(0.2944)		
CAD	-0.0275***	-4.8147***	-5.3974***	2030	0.1721
	(0.0050)	(0.4382)	(0.3029)		
EUR	-0.0202***	-4.8496***	-4.9312***	2030	0.1429
	(0.0045)	(0.4215)	(0.3024)		
JPY	-0.0395***	-4.6731***	-6.3303***	2030	0.1693
	(0.0054)	(0.5024)	(0.3814)		
NZD	-0.0286***	-6.6486***	-5.7917***	2030	0.2012
	(0.0051)	(0.3326)	(0.3191)		
NOK	-0.0192***	-4.1850***	-4.8424***	2030	0.1553
	(0.0043)	(0.3495)	(0.2837)		
SEK	-0.0217***	-4.6015***	-4.5942***	1934	0.1319
	(0.0049)	(0.3887)	(0.3141)		
CHF	-0.0123***	-2.4595***	-2.7491***	2030	0.0514
	(0.0033)	(0.3880)	(0.3352)		
GBP	-0.0230***	-3.6179***	-5.1773***	2030	0.1271
	(0.0042)	(0.4102)	(0.3262)		
USD	-0.0114***	-6.4713***	-4.6688***	2030	0.1685
	(0.0034)	(0.4045)	(0.3203)		

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 Krone (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. $\hat{\eta}_{j,t}$ is an proxy of the treasury liquidity, $i^R_{j,t}$ is the home minus foreign interest rates. Δ is a difference operator. The sample period is 1999M1-2017M12. Germany government interest rate is used for EUR case. Standard errors in parentheses are simple OLS standard errors. *, **, 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 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	-0.0359***	-4.3213***	-0.3505***	1950	0.1274
	(0.0056)	(0.2811)	(0.0682)		
CAD	-0.0288***	-4.3093***	-0.2645***	2030	0.1097
	(0.0051)	(0.3003)	(0.0655)		
DEM	-0.0231***	-3.5943***	-0.1972***	2030	0.0819
	(0.0047)	(0.2906)	(0.0651)		
JPY	-0.0337***	-5.1689***	-0.1476**	2030	0.0957
	(0.0055)	(0.3847)	(0.0578)		
NZD	-0.0313***	-1.6212***	-0.0789	2030	0.0322
	(0.0056)	(0.2711)	(0.0712)		
NOK	-0.0181***	-3.3691***	-0.1318***	2030	0.0779
	(0.0043)	(0.2738)	(0.0503)		
SEK	-0.0260***	-3.1307***	-0.1204**	1934	0.0676
	(0.0050)	(0.2989)	(0.0603)		
CHF	-0.0101***	-1.8790***	-0.2256***	2030	0.0225
	(0.0032)	(0.3182)	(0.0728)		
GBP	-0.0229***	-3.5205***	-0.3435***	2030	0.0783
	(0.0043)	(0.2925)	(0.0731)		
USD	-0.0143***	-3.4732***	-0.1367**	2030	0.0629
	(0.0036)	(0.3261)	(0.0558)		

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 Krone (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. $\hat{\eta}_{j,t}$ is an proxy of the treasury liquidity, $i^R_{j,t}$ is the home minus foreign interest rates. Δ is a difference operator. The sample period is 1999M1-2017M12. Germany government interest rate is used for EUR case. Standard errors in parentheses are simple OLS standard errors. *, **, 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 appendix.

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

Home Currency (1)	$\Delta\hat{\eta}_{j,t}$ (2)	Within R^2 (3)	$\Delta\hat{\eta}_{j,t}$ (4)	Within R^2 (5)
	1999M1-2007M12		2008M1-2017M12	
AUD	-3.4161***	0.0990	-6.4067***	0.2990
	(0.7579)		(0.5424)	
CAD	-2.6968***	0.0916	-5.9904***	0.2878
	(0.7458)		(0.5377)	
EUR	-2.5990***	0.0446	-5.7893***	0.2549
	(0.6800)		(0.5372)	
JPY	-1.3979*	0.0411	-6.1979***	0.3270
	(0.8463)		(0.6211)	
NZD	-4.4151***	0.0977	-7.7741***	0.3265
	(0.5535)		(0.4213)	
NOK	-3.5898***	0.0906	-5.1350***	0.2572
	(0.6367)		(0.4299)	
SEK	-2.7804***	0.0744	-5.9492***	0.2348
	(0.6250)		(0.5018)	
CHF	-0.9278	0.0281	-3.1122***	0.0920
	(0.6463)		(0.5075)	
GBP	-4.0058***	0.0996	-3.9298***	0.1961
	(0.5768)		(0.5698)	
USD	-4.0426***	0.0805	-7.3408***	0.3191
	(0.6493)		(0.5056)	

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 Krone (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. $\hat{\eta}_{j,t}$ is an proxy of the treasury liquidity, $i^R_{j,t}$ is the home minus foreign interest rates. Δ 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 simple OLS standard errors. *, **, 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 appendix.

Table 2D:

Estimation result of $\Delta s_{j,t} = \alpha_j + \beta_1 q_{j,t-1} + \beta_2(\Delta\hat{\eta}_{j,t}) + \beta_3(\Delta i^R_{j,t}) + \beta_4(\hat{\eta}_{j,t-1}) + \beta_4(i^R_{j,t-1}) + u_{j,t}$ using one-month forward rates and one-month government yields

Home Currency (1)	$q_{i,t-1}$ (2)	$\Delta\hat{\eta}_{j,t}$ (3)	$\Delta i^R_{j,t}$ (4)	Observations (5)
AUD	-0.0543***	-7.2292	-22.9042***	360
	(0.0177)	(5.9863)	(8.1561)	
CAD	-0.0299***	-12.7346***	-29.1263***	1228
	(0.0061)	(3.4033)	(4.4743)	
DEM	-0.0826***	-18.6085***	-20.0382***	609
	(0.0141)	(5.3202)	(6.4542)	
JPY	-0.1023***	-23.3412***	-11.6606	462
	(0.0142)	(6.6937)	(13.4730)	
NZD	-0.0331***	-18.7123***	-28.5861***	1228
	(0.0069)	(3.2412)	(4.9095)	
SEK	-0.0332***	-14.9686***	-17.2230***	1228
	(0.0068)	(3.1553)	(4.2900)	
CHF	-0.0572***	-10.8859**	9.7523*	731
	(0.0096)	(4.8537)	(5.2722)	
GBP	-0.0221***	-8.1728***	-19.2894***	1228
	(0.0060)	(2.7300)	(4.7235)	
USD	-0.0254***	-17.1716***	-15.1574***	1228
	(0.0056)	(2.7805)	(4.2191)	

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 Krone (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. $\hat{\eta}_{j,t}$ is an proxy of the treasury liquidity, $i^R_{j,t}$ is the home minus foreign interest rates. Δ is a difference operator. The sample period is 1999M1-2017M12. Germany government interest rate is used for EUR case.
Standard errors in parentheses are simple OLS standard errors. *, **, 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 appendix.

Table 3:

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

Home Currency (1)	$q_{j,t-1}$ (2)	$\Delta\hat{\eta}_{j,t}$ (3)	$\Delta i^R_{j,t}$ (4)	Observations (5)
AUD	-0.0419	-34.4415***	-8.3779***	640
	(0.0341)	(13.1138)	(1.5425)	
CAD	-0.0775***	-22.2907***	-7.0531***	655
	(0.0223)	(7.6662)	(0.9436)	
EUR	-0.0554***	-17.9122***	-6.3889***	634
	(0.0197)	(6.5435)	(0.8195)	
JPY	-0.0813***	-11.4711	-7.3664***	655
	(0.0214)	(7.2497)	(0.7204)	
NZD	-0.0954***	2.2629	-2.0199	655
	(0.0170)	(2.9688)	(1.2461)	
NOK	-0.0844***	-4.8606	-4.9726***	634
	(0.0190)	(3.6761)	(0.4569)	
SEK	-0.0621***	-6.4372***	-4.3294***	615
	(0.0158)	(1.9788)	(0.5963)	
CHF	-0.0626***	1.2634	-2.0322	655
	(0.0114)	(5.1033)	(1.2380)	
GBP	-0.0897***	-1.4137	-7.5410***	634
	(0.0169)	(8.0241)	(2.3728)	
USD	-0.0266**	-17.1298**	-4.1847***	655
	(0.0152)	(8.3334)	(0.6234)	

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 Krone (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. $\hat{\eta}^{IV}_{j,t}$ is an proxy of the treasury liquidity, $i^R_{j,t}$ is the home minus foreign interest rates. Δ is a difference operator. The instruments for treasury liquidity are change and the level of log of general government debt to GDP for home country and each foreign country *j* and the log of the VIX index. The sample period is 1999Q1-2017Q4. Germany government interest rate and debt to GDP are used for EUR case.

Standard errors in parentheses are simple OLS standard errors. *, **, 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 appendix.

Table 4A:
Estimation result of
$$\Delta s_{j,t} = \alpha_j + \beta_1 q_{j,t-1} + \beta_2 \Delta\hat{\lambda}_{j,t} + \beta_3 \Delta\hat{\tau}_{j,t} + \beta_4 \Delta\hat{l}^R_{j,t} + \beta_5 \Delta i^R_{j,t} + \beta_6 \hat{\lambda}_{j,t-1} + \beta_7 \hat{\tau}_{j,t-1} + \beta_8 \hat{l}^R_{j,t-1} + \beta_9 i^R_{j,t-1} + u_{j,t}$$

Home Currency (1)	$\Delta\hat{\lambda}_{i,t+1}$ (2)	$\Delta\hat{\tau}_{i,t+1}$ (3)	$\Delta\hat{\lambda}_{i,t+1}$ (4)	$\Delta\hat{\tau}_{i,t+1}$ (5)	$\Delta\hat{l}_{i,t+1}$ (6)
	Full sample, no default risk		Post 2008, with default risk		
AUD	-6.3786***	-2.6578***	-7.4617***	-3.1458***	14.7568***
	(0.4874)	(0.7392)	(0.7127)	(0.9469)	(1.5824)
CAD	-4.9935***	-5.2895***	-8.8409***	-6.5673***	7.9127***
	(0.5489)	(0.6877)	(1.3665)	(1.6852)	(2.0209)
EUR	-4.9026***	-5.0570***	-6.6893***	-4.2515***	8.8973***
	(0.4672)	(0.6226)	(0.6727)	(0.8024)	(1.3775)
JPY	-4.6560***	-4.8883***	-7.7275***	-4.1048***	10.7038***
	(0.6208)	(0.8510)	(0.9135)	(1.1105)	(1.8018)
NZD	-7.0843***	-5.8045***	-8.7088***	-5.7615***	12.8063***
	(0.3664)	(0.6472)	(0.5436)	(0.8463)	(1.5128)
NOK	-4.0191***	-5.2592***	-5.4087***	-5.9530***	4.4098***
	(0.3626)	(0.6374)	(0.5015)	(0.8877)	(1.4844)
SEK	-4.4944***	-5.3330***	-5.8851***	-4.4987***	7.9955***
	(0.4339)	(0.7605)	(0.6584)	(1.0314)	(1.4848)
CHF	-3.2245***	-1.1683*	-3.3282***	-1.2909	5.7111***
	(0.4876)	(0.6875)	(0.9646)	(1.0829)	(1.8631)
GBP	-4.4865***	-1.5006**	-6.7053***	-0.5773	6.2626***
	(0.4582)	(0.6950)	(0.7283)	(0.9259)	(1.4449)
USD	-6.4019***	-6.6687***	-9.0553***	-3.1577***	12.8399***
	(0.4757)	(0.7248)	(0.7470)	(0.9216)	(1.2657)

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 Krone (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. $\hat{\tau}_{j,t}$ is a proxy of currency derivative friction, $\hat{l}^R_{j,t}$ is a proxy of home minus foreign default risk, $\hat{\lambda}_{j,t}$ is a proxy of the treasury liquidity after adjusting for derivative market friction and default risk, $i^R_{j,t}$ is the home minus foreign interest rates. Δ 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 simple OLS standard errors. *, **, 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 appendix.

Table 4B

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	$\hat{\lambda}_{j,t}$	$\hat{\tau}_{j,t}$	$\hat{l}^R_{j,t}$	$(\hat{\eta}+\hat{l}^R)_{j,t}$	$(\hat{\eta}-\hat{\tau})_{j,t}$	$(\hat{\tau}-\hat{l}^R)_{j,t}$
(1)	(2)	(3)	(4)	(5)	(6)	(7)
AUD	-4.9760***	-1.3686*	10.0618***	-4.6872***	-6.1164***	-4.5814***
	(0.6645)	(0.7668)	(1.5815)	(0.6059)	(0.4796)	(0.8262)
CAD	-4.2440***	-4.4386***	1.0784	-5.4797***	-4.1746***	-1.9662*
	(1.0551)	(0.6822)	(1.7123)	(1.0577)	(0.5458)	(1.1279)
EUR	-3.5509***	-3.2480***	2.3930*	-4.3451***	-3.7916***	-2.7032***
	(0.5389)	(0.6057)	(1.2477)	(0.5252)	(0.4511)	(0.6481)
JPY	-5.5731***	-5.8131***	4.8197***	-5.1390***	-4.7220***	-6.3243***
	(0.7969)	(0.8654)	(1.7943)	(0.6398)	(0.6317)	(0.9653)
NZD	-6.7973***	-3.9588***	5.4492***	-6.3109***	-6.5900***	-5.1850***
	(0.5132)	(0.6967)	(1.6455)	(0.4595)	(0.3661)	(0.8216)
NOK	-4.3269***	-3.1095***	-1.0486	-5.0067***	-3.0522***	-3.4877***
	(0.4698)	(0.6260)	(1.4869)	(0.4350)	(0.3507)	(0.8189)
SEK	-3.9706***	-4.5534***	4.1664***	-4.6545***	-4.1911***	-4.1806***
	(0.5963)	(0.7773)	(1.4488)	(0.5335)	(0.4367)	(0.8047)
CHF	-2.1524***	-1.5411**	2.4804	-1.7904***	-3.3224***	-2.2370**
	(0.8157)	(0.6953)	(1.6146)	(0.5900)	(0.4868)	(0.8830)
GBP	-5.2416***	-0.6735	1.3490	-3.8347***	-4.3517***	-0.6427
	(0.6696)	(0.7033)	(1.3893)	(0.5761)	(0.4516)	(0.7836)
USD	-5.3784***	-6.0583***	5.5026***	-4.8380***	-6.1387***	-4.8924***
	(0.6780)	(0.7546)	(1.2106)	(0.5424)	(0.4848)	(0.7566)

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 Krone (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. $\hat{\tau}_{j,t}$ is a proxy of currency derivative friction, $\hat{l}^R_{j,t}$ is a proxy of home minus foreign default risk, $\hat{\lambda}_{j,t}$ is a proxy of the treasury liquidity after adjusting for derivative market friction and default risk, $i^R_{j,t}$ is the home minus foreign interest rates. Δ is a difference operator. The sample period is 1999M1-2017M12. Regressions involving default risk $\hat{l}^R_{j,t}$ are only estimated through 2008M1-2017M12 period. Germany default risk is used for EUR case.

Standard errors in parentheses are simple OLS standard errors. *, **, 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 appendix.

Table 4C

$$1=\frac{\operatorname{var}(\Delta\hat{\lambda}_t)}{\operatorname{var}(\Delta\hat{\eta}_t)}+\frac{\operatorname{var}(\Delta\hat{\tau}_t)}{\operatorname{var}(\Delta\hat{\eta}_t)}+\frac{\operatorname{var}(\Delta\hat{l}_t^R)}{\operatorname{var}(\Delta\hat{\eta}_t)}+2\frac{\operatorname{cov}(\Delta\hat{\lambda}_t,\Delta\hat{\tau}_t)}{\operatorname{var}(\Delta\hat{\eta}_t)}-2\frac{\operatorname{cov}(\Delta\hat{\tau}_t,\Delta\hat{l}_t^R)}{\operatorname{var}(\Delta\hat{\eta}_t)}-2\frac{\operatorname{cov}(\Delta\hat{l}_t^R,\Delta\hat{\lambda}_t)}{\operatorname{var}(\Delta\hat{\eta}_t)}$$

Variance share of each of the terms above:

Home Currency	$\frac{\operatorname{var}(\Delta\hat{\lambda}_t)}{\operatorname{var}(\Delta\hat{\eta}_t)}$	$\frac{\operatorname{var}(\Delta\hat{\tau}_t)}{\operatorname{var}(\Delta\hat{\eta}_t)}$	$\frac{\operatorname{var}(\Delta\hat{l}_t^R)}{\operatorname{var}(\Delta\hat{\eta}_t)}$	$\frac{2\operatorname{cov}(\Delta\hat{\lambda}_t,\Delta\hat{\tau}_t)}{\operatorname{var}(\Delta\hat{\eta}_t)}$	$\frac{2\operatorname{cov}(\Delta\hat{\tau}_t,\Delta\hat{l}_t^R)}{\operatorname{var}(\Delta\hat{\eta}_t)}$	$\frac{2\operatorname{cov}(\Delta\hat{l}_t^R,\Delta\hat{\lambda}_t)}{\operatorname{var}(\Delta\hat{\eta}_t)}$
(1)	(2)	(3)	(4)	(5)	(6)	(7)
AUD	74%	34%	13%	-7%	-4%	17%
CAD	127%	45%	43%	-38%	-5%	81%
EUR	116%	47%	19%	-43%	-7%	45%
JPY	66%	33%	14%	11%	1%	23%
NZD	85%	24%	8%	-2%	1%	14%
NOK	96%	23%	9%	-10%	2%	16%
SEK	86%	25%	13%	-3%	-4%	26%
CHF	69%	35%	15%	13%	1%	31%
GBP	81%	34%	15%	-6%	1%	22%
USD	75%	36%	23%	3%	0%	37%

The 10 currencies used are Australian Dollar (AUD), Canadian Dollar (CAD), Euro (EUR), Japanese Yen (JPY), New Zealand Dollar (NZD), Norwegian Krone (NOK), Swedish Krone (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. $\hat{\tau}_{j,t}$ is a proxy of currency derivative friction, $\hat{l}_{j,t}^R$ is a proxy of home minus foreign default risk, $\hat{\lambda}_{j,t}$ is a proxy of the treasury 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 5:
Estimation result of
$$\Delta s_{j,t} = \alpha_j + \beta_1 q_{j,t-1} + \beta_2 \Delta \hat{\tau}_{j,t} + \beta_3 \Delta \hat{\gamma}_t + \beta_4 \Delta \hat{\gamma}^*_{j,t} + \beta_5 \Delta i^R_{j,t} + \beta_6 \hat{\gamma}_{t-1} + \beta_7 \hat{\gamma}^*_{j,t-1} + \beta_8 i^R_{j,t-1} + u_{j,t}$$

Home Currency (1)	$\Delta\hat{\gamma}^*_{j,t}$ (2)	$\Delta\hat{\gamma}_{j,t}$ (3)	$\Delta\hat{\tau}_{i,t}$ (4)	Within R^2 (5)
AUD	5.7203***	-7.0727***	-2.4064***	0.2169
	(0.5781)	(0.6227)	(0.7481)	
CAD	4.8626***	-6.2014***	-5.3198***	0.2059
	(0.5658)	(1.0105)	(0.6909)	
EUR	4.8673***	-5.0422***	-5.1449***	0.1467
	(0.4882)	(0.7240)	(0.7097)	
JPY	4.7555***	-2.3376	-4.6963***	0.1740
	(0.6259)	(2.1228)	(0.8670)	
NZD	6.0903***	-7.3252***	-5.4167***	0.2151
	(0.7027)	(0.3844)	(0.6795)	
NOK	5.8821***	-3.3693***	-5.1587***	0.1675
	(0.5571)	(0.3891)	(0.6349)	
SEK	5.0511***	-3.4433***	-5.4054***	0.1364
	(0.4982)	(0.6852)	(0.7621)	
CHF	3.3013***	-2.7337***	-1.2117*	0.0574
	(0.5358)	(0.8891)	(0.6901)	
GBP	5.2858***	-3.6830***	-1.1542	0.1400
	(0.5547)	(0.5526)	(0.7082)	
USD	6.4273***	-5.8857***	-6.4659***	0.1882
	(0.5555)	(0.6384)	(0.7391)	

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 Krone (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. $\hat{\tau}_{j,t}$ is a proxy of currency derivative friction, $\hat{\gamma}^*_{j,t}$ is a proxy of foreign treasury liquidity, $\hat{\gamma}_{j,t}$ is a proxy of the home treasury liquidity, $i^R_{j,t}$ is the home minus foreign interest rates. Δ is a difference operator. The sample period is 1999M1-2017M12. Germany government interest rate is used for EUR case.
Standard errors in parentheses are simple OLS standard errors. *, **, 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 appendix.

Appendix of Liquidity and Exchange Rates: An Empirical Investigation

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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:

$$(.1) \qquad E_0\left\{\sum_{t=0}^{\infty}\beta^t\left[u\left(c_t\right)+v\left(\frac{M_{H,t}}{P_t},\frac{B_{H,t}}{P_t},\frac{S_tB^*_{H,t}}{P_t}\right)\right]\right\}.$$

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:

$$(.2) \qquad v\left(\frac{M_{H,t}}{P_t},\frac{B_{H,t}}{P_t},\frac{S_t B^*_{H,t}}{P_t}\right)=\frac{1}{1-\gamma}\left[\left(\frac{M_{H,t}}{P_t}\right)^{\frac{\varepsilon-1}{\varepsilon}}+\left(\frac{\kappa B_{H,t}}{P_t}\right)^{\frac{\varepsilon-1}{\varepsilon}}+\left(\frac{\eta S_t B^*_{H,t}}{P_t}+\mu\right)^{\frac{\varepsilon-1}{\varepsilon}}\right]^{\frac{(1-\gamma)\varepsilon}{\varepsilon-1}}$$

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

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

$$(.3) \qquad \begin{aligned} &P_t c_t + M_{H,t} + B_{H,t} + B^m_{H,t} + S_t B^*_{H,t} + S_t B^{*m}_{H,t} \\ &= P_t y_t + M_{H,t-1} + (1+i_{t-1}) B_{H,t-1} + (1+i^m_{t-1}) B^m_{H,t-1} + S_t (1+i^*_t) B^*_{H,t-1} + S_t (1+i^{*m}_{t-1}) B^{*m}_{H,t-1} \end{aligned}$$

Households maximize (A.1) subject to (A.3), and to the constraints $M_{H,t}\ge 0$, $B_{H,t}\ge 0$ and $B^*_{H,t}\ge 0$. 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:

$$(.4) \quad -\frac{1}{P_t}u'\left(c_t\right)+\frac{1}{P_{t+1}}\beta E_t u'\left(c_{t+1}\right)+\frac{1}{P_t}v_M\left(\frac{M_{H,t}}{P_t},\frac{B_{H,t}}{P_t},\frac{S_t B^*_{H,t}}{P_t}\right)\leq 0$$

$$(.5) \quad -\frac{1}{P_t}u'\left(c_t\right)+\frac{1+i_t}{P_{t+1}}\beta E_t u'\left(c_{t+1}\right)+\frac{1}{P_t}v_B\left(\frac{M_{H,t}}{P_t},\frac{B_{H,t}}{P_t},\frac{S_t B^*_{H,t}}{P_t}\right)\leq 0$$

$$(.6) \quad -\frac{1}{P_t}u'\left(c_t\right)+\frac{1+i^m_t}{P_{t+1}}\beta E_t u'\left(c_{t+1}\right)=0$$

$$(.7) \quad -\frac{S_t}{P_t}u'\left(c_t\right)+\frac{1+i^*_t}{P_{t+1}}\beta E_t S_{t+1} u'\left(c_{t+1}\right)+\frac{S_t}{P_t}v_{B^*}\left(\frac{M_{H,t}}{P_t},\frac{B_{H,t}}{P_t},\frac{S_t B^*_{H,t}}{P_t}\right)\leq 0$$

$$(.8) \quad -\frac{S_t}{P_t}u'\left(c_t\right)+\frac{1+i^{*m}_t}{P_{t+1}}\beta E_t S_{t+1} u'\left(c_{t+1}\right)=0$$

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:

$$(.9) \quad v^*\left(\frac{M^*_{F,t}}{P^*_t},\frac{B^*_{F,t}}{P^*_t},\frac{S^{-1}_t B_{F,t}}{P^*_t}\right)=\frac{1}{1-\gamma}\left[\left(\frac{M^*_{F,t}}{P^*_t}\right)^{\frac{\varepsilon-1}{\varepsilon}}+\left(\frac{\kappa B^*_{F,t}}{P^*_t}\right)^{\frac{\varepsilon-1}{\varepsilon}}+\left(\frac{\eta S^{-1}_t B_{F,t}}{P^*_t}+\mu\right)^{\frac{\varepsilon-1}{\varepsilon}}\right]^{\frac{(1-\gamma)\varepsilon}{\varepsilon-1}}.$$

The first-order conditions for the foreign household are:

$$(.10) \quad -\frac{1}{P^*_t}u'\left(c^*_t\right)+\frac{1}{P^*_{t+1}}\beta E_t u'\left(c^*_{t+1}\right)+\frac{1}{P^*_t}v^*_{M^*}\left(\frac{M^*_{F,t}}{P^*_t},\frac{B^*_{F,t}}{P^*_t},\frac{S^{-1}_t B_{F,t}}{P^*_t}\right)\leq 0$$

$$(.11) \quad -\frac{1}{P^*_t}u'\left(c^*_t\right)+\frac{1+i^*_t}{P^*_{t+1}}\beta E_t u'\left(c^*_{t+1}\right)+\frac{1}{P^*_t}v^*_{B^*}\left(\frac{M^*_{F,t}}{P^*_t},\frac{B^*_{F,t}}{P^*_t},\frac{S^{-1}_t B_{F,t}}{P^*_t}\right)\leq 0$$

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

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

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

Equations (A.6) and (A.8) imply the relationship:

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

We will take first-order log approximations, hence setting the foreign-exchange risk premium equal to a constant. When we do that, we arrive at the equation in the text that says uncovered interest rate parity holds for the market rates of return:

(.15) $$i_t^{*m}+E_t s_{t+1}-s_t-i_t^m=0$$

Equations (A.12) and (A.14) imply the same relationship. Note that we cannot claim that our model can account for the empirical failure of uncovered interest parity using typically riskless market interest rates such as LIBOR.

Assume equations (A.4) and (A.5) hold with equality, so that the home agent holds positive amounts of home money and home government bonds. (A.6) implies:

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

Substitute this into (A.5), and cancel terms to get:

$$(.17)\qquad \frac{1+i_t}{1+i_t^m}+\frac{v_B\left(\frac{M_{H,t}}{P_t},\frac{B_{H,t}}{P_t},\frac{S_tB_{H,t}^*}{P_t}\right)}{u'(c_t)}=1.$$

Similarly, substituting (A.16) into (A.4) gives us:

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

Rearranging these two equations, we find:

$$(.18)\qquad i_t^m-i_t=\frac{v_B\left(\frac{M_{H,t}}{P_t},\frac{B_{H,t}}{P_t},\frac{S_tB_{H,t}^*}{P_t}\right)}{v_M\left(\frac{M_{H,t}}{P_t},\frac{B_{H,t}}{P_t},\frac{S_tB_{H,t}^*}{P_t}\right)-v_B\left(\frac{M_{H,t}}{P_t},\frac{B_{H,t}}{P_t},\frac{S_tB_{H,t}^*}{P_t}\right)}i_t.$$

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

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

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.15) arrive exactly at the model given in the text, in which

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

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.17), 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.2), we can derive that the liquidity premium from the right-hand-side of equation (A.18) is given by:

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

As $\varepsilon \to \infty$, 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
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	DS:CNTBB1Y	BBG:GTDEM1Y Govt	BBG:GTJPY 1Y Govt	BBG:GTNZD1Y Govt DS:NZGBY1Y	BBG:ST3XY Index	Sveriges Riksbank website, Treasury bills SE12M BBG:BV010259 Index	Swiss National Bank, spot interest rate for 1Y govt bond	BBG:GTGBP1Y Govt	BBG:GB12 Govt FRED
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
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
*** there are missing values at 2009m7-2009m11, 2010m11-2011m3

Appendix A3: Summary statistics

All the summary statistics are reported as the value it is, except for gobt debt to GDP. For example, i of .04469 represents 4.469% 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))	2079	-.77601	1.5141	-4.6713	1.0913	2079	-.85401	1.5082	-4.7989	.93826
q (ln(Q))	2070	-.80917	1.5305	-4.7661	1.0183	2077	-.85347	1.5282	-4.8547	.96151
i^R	1961	.01974	.01587	-.02489	.06076	2057	.00057	.01659	-.04146	.05848
$f-s$	2079	.02177	.01765	-.02474	.07001	2079	9.6e-05	.01817	-.0542	.06112
$\hat{\eta}$	1961	.00254	.00315	-.0099	.01605	2057	-.00046	.00313	-.01576	.01271
$\hat{\tau}$	2052	.00158	.00204	-.00381	.01123	1854	.00076	.00203	-.00528	.01252
$\hat{l}^R$	1130	.00031	.00116	-.00264	.00603	539	.00032	.00136	-.00474	.00381
$\hat{\lambda}$	1120	.00089	.00322	-.01027	.01468	533	-.00034	.00333	-.0128	.00642
$\hat{\eta}-\hat{\tau}$	1946	.00092	.00308	-.01109	.01498	1842	-.00111	.00324	-.0151	.01597
$(IRS-i)$	1971	.0041	.00273	.00047	.01576	1854	.0022	.00118	-.00071	.00708
i	1971	.04022	.01528	.01502	.06682	2079	.02371	.01633	.00409	.06062
IRS	2079	.04469	.01691	.01637	.07984	1854	.02233	.01337	.00461	.0572
Govt debt to GDP (%)	693	19.036	9.0964	8.1	37.5	693	64.868	7.6034	48.8	80.3

	EUR					**JPY**				
	Obs	Mean	SD	Min	Max	Obs	Mean	SD	Min	Max
s (ln(S))	2079	-.53093	1.523	-4.4569	1.2114	2079	4.1016	.821	2.3781	5.5125
q (ln(Q))	2077	-.52131	1.5432	-4.5051	1.2519	2077	4.1631	.82875	2.3376	5.5947
i^R	2057	-.00647	.01601	-.04241	.04642	2057	-.02428	.01965	-.06993	.00973
$f-s$	2079	-.00761	.01747	-.0481	.04826	2079	-.02747	.02024	-.07911	.01069
$\hat{\eta}$	2057	-.00107	.00299	-.01497	.01071	2057	-.00312	.00305	-.02026	.00982
$\hat{\tau}$	2038	-.00104	.00215	-.0134	.00451	2052	-.0009	.00234	-.00959	.00743
$\hat{l}^R$	1186	-.0004	.00116	-.00726	.00513	1193	.00021	.00119	-.00703	.00512
$\hat{\lambda}$	1176	.00035	.00336	-.01444	.01521	1183	-.0018	.00332	-.0189	.01371
$\hat{\eta}-\hat{\tau}$	2018	-5.2e-05	.00324	-.0131	.01477	2030	-.00224	.00299	-.01784	.01367
$(IRS-i)$	2061	.00325	.00226	.00063	.01559	2079	.00129	.00083	-.00044	.00408
i	2079	.01733	.01748	-.00919	.05043	2079	.0013	.00226	-.00328	.00782
IRS	2061	.02046	.01748	-.00329	.05381	2079	.00259	.00272	-.0014	.01081
Govt debt to GDP (%)	648	68.422	6.9687	57.2	81.1	693	158.85	31.604	94.7	201.5

	NZD					NOK				
	Obs	Mean	SD	Min	Max	Obs	Mean	SD	Min	Max
s (ln(S))	2079	-.60113	1.5232	-4.5581	1.297	2079	1.0655	1.4958	-3.0626	2.639
q (ln(Q))	2070	-.63279	1.5396	-4.6495	1.2376	2077	1.0561	1.5176	-3.1559	2.6345
i^R	2057	.02319	.01578	-.02206	.06957	2057	.00885	.01838	-.0409	.06993
$f-s$	2079	.02592	.01746	-.02157	.07911	2079	.00873	.02025	-.0466	.07268
$\hat{\eta}$	2057	.00291	.00462	-.01493	.02001	2057	-.00012	.00364	-.02142	.01513
$\hat{\tau}$	2052	.00141	.00235	-.00705	.01365	2052	-.0011	.0019	-.01101	.00532
$\hat{l}^R$	1082	.00085	.00138	-.00248	.00817	1063	-.00092	.00133	-.00846	.00126
$\hat{\lambda}$	1072	.00066	.00493	-.01618	.0189	1053	.00027	.00388	-.01807	.0163
$\hat{\eta}-\hat{\tau}$	2030	.0015	.00508	-.01629	.01784	2030	.00095	.00364	-.01602	.01752
$(IRS-i)$	2079	.00466	.00526	-.01261	.02057	2079	.00417	.00304	-.00223	.0172
i	2079	.04393	.01719	.01764	.07739	2079	.03118	.02054	.00419	.07018
IRS	2079	.04859	.02058	.01966	.08853	2079	.03535	.02183	.00779	.07695
Govt debt to GDP (%)	693	26.996	5.7755	15.6	36.8	648	36.215	7.6001	22.7	51.9

	SEK					CHF				
	Obs	Mean	SD	Min	Max	Obs	Mean	SD	Min	Max
s (ln(S))	2079	1.1928	1.4848	-2.8972	2.7523	2079	-.91444	1.5096	-4.8794	.99034
q (ln(Q))	2077	1.2008	1.5043	-2.9392	2.8171	2077	-.9079	1.5372	-4.9333	1.1008
i^R	1977	-.00444	.01679	-.04723	.04672	2057	-.01589	.01574	-.05656	.03556
$f-s$	2079	-.00422	.01847	-.05328	.0476	2079	-.01973	.01665	-.06185	.03662
$\hat{\eta}$	1977	.00014	.00348	-.01473	.01576	2057	-.00379	.00345	-.02057	.00872
$\hat{\tau}$	2052	-.00089	.00175	-.01164	.00636	2052	-.00057	.00209	-.00925	.00705
$\hat{l}^R$	1138	-.00019	.00116	-.00423	.00589	914	-.00014	.00126	-.00416	.00846
$\hat{\lambda}$	1053	.00177	.00343	-.01515	.0154	904	-.00373	.00303	-.0163	.01242
$\hat{\eta}-\hat{\tau}$	1950	.00102	.00338	-.0137	.01469	2030	-.00325	.00293	-.01752	.01285
$(IRS-i)$	1989	.00424	.00247	8.5e-05	.01221	2079	.00039	.00152	-.00256	.00701
i	1989	.01959	.01748	-.00909	.04684	2079	.00886	.01231	-.00984	.03827
IRS	2079	.02351	.01766	-.0056	.05458	2079	.00925	.01328	-.01055	.0403
Govt debt to GDP (%)	693	44.896	7.1797	35	66.8	693	37.626	7.534	29	48.9

	GBP					USD				
	Obs	Mean	SD	Min	Max	Obs	Mean	SD	Min	Max
s (ln(S))	2079	-1.6056	1.4512	-5.5125	-.18843	2079	-1.0776	1.4991	-4.8965	.73109
q (ln(Q))	2077	-1.6092	1.4743	-5.5947	-.04659	2077	-1.091	1.5208	-5.1398	.76104
i^R	2057	.00331	.01786	-.04241	.06068	2057	-.00384	.0185	-.05299	.0593
$f-s$	2079	.00435	.01924	-.0444	.06384	2079	-.00183	.02036	-.06144	.07129
$\hat{\eta}$	2057	.00109	.00316	-.01091	.01619	2057	.00201	.00347	-.01161	.02142
$\hat{\tau}$	2052	-.00031	.00196	-.01365	.00988	2052	.00112	.00185	-.00387	.01217
$\hat{l}^R$	1004	.0003	.00131	-.00461	.00663	949	-.00021	.00147	-.00641	.00423
$\hat{\lambda}$	994	.0014	.00339	-.00734	.01807	940	2.8e-05	.00329	-.01428	.01478
$\hat{\eta}-\hat{\tau}$	2030	.0014	.00314	-.01052	.01602	2030	.00084	.00327	-.01282	.01486
$(IRS-i)$	2079	.00457	.00276	4.1e-05	.01748	2079	.00411	.00277	.00046	.01579
i	2079	.02615	.02176	-3.0e-05	.06195	2079	.01976	.01914	.00086	.06057
IRS	2079	.03072	.02303	.0031	.0683	2079	.02386	.021	.00261	.075
Govt debt to GDP (%)	648	59.218	22.306	33.7	87.9	693	72.21	19.288	46.9	98.7

Variance covariance table of $\Delta\hat{\eta}_{j,t}, \Delta\hat{\lambda}_{j,t}, \Delta\hat{\tau}_{j,t}, \Delta\hat{l}^{R}_{j,t},$

Home	$var(\Delta\hat{\eta}_t)$	$var(\Delta\hat{\tau}_t)$	$var(\Delta-\hat{l}^R_t)$	$var(\Delta\hat{\lambda}_t)$	$cov(\Delta\hat{\lambda}_t, \Delta\hat{\tau}_t)$	$cov(\Delta-\hat{l}^R_t, \Delta\hat{\lambda}_t)$	$cov(\Delta\hat{\tau}_t, \Delta-\hat{l}^R_t)$
AUD	2.96E-06	1.00E-06	3.70E-07	2.20E-06	5.30E-08	-2.50E-07	-1.10E-07
CAD	1.26E-06	5.60E-07	5.40E-07	1.60E-06	2.90E-08	-5.10E-07	-2.40E-07
EUR	2.33E-06	1.10E-06	4.40E-07	2.70E-06	7.60E-08	-5.30E-07	-5.00E-07
JPY	3.33E-06	1.10E-06	4.60E-07	2.20E-06	-1.40E-08	-3.90E-07	1.90E-07
NZD	6.74E-06	1.60E-06	5.10E-07	5.70E-06	-1.80E-08	-4.60E-07	-5.80E-08
NOK	4.70E-06	1.10E-06	4.20E-07	4.50E-06	-5.20E-08	-3.80E-07	-2.30E-07
SEK	3.15E-06	8.00E-07	4.20E-07	2.70E-06	6.40E-08	-4.10E-07	-4.10E-08
CHF	2.88E-06	1.00E-06	4.30E-07	2.00E-06	-1.30E-08	-4.50E-07	1.90E-07
GBP	3.85E-06	1.30E-06	5.70E-07	3.10E-06	-1.00E-08	-4.30E-07	-1.20E-07
USD	3.60E-06	1.30E-06	8.20E-07	2.70E-06	1.70E-09	-6.60E-07	4.60E-08

The 10 currencies used are Australian Dollar (AUD), Canadian Dollar (CAD), Euro (EUR), Japanese Yen (JPY), New Zealand Dollar (NZD), Norwegian Krone (NOK), Swedish Krone (SEK), Swiss Franc (CHF), British Pound (GBP) and United States Dollar (USD). Each row represents a regression estimation using the first column currency as the home currency and the other 9 currencies as foreign currency j. . $\hat{\eta}_{j,t}$ is a proxy of relative treasury liquidity, $\hat{\tau}_{j,t}$ is a proxy of currency derivative friction, $\hat{l}^R_{j,t}$ is a proxy of home minus foreign default risk, $\hat{\lambda}_{j,t}$ is a proxy of the treasury liquidity after adjusting for derivative market friction and default risk, Δ is a difference operator. The sample period is 2008M1-2017M12.