Foreign Safe Asset Demand and the Dollar Exchange Rate

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Abstract

An increase in the convenience yield that foreign investors derive from holding U.S. Treasurys will be reflected in an appreciation of the US dollar. We develop theory to link foreign investors’ demand for safe U.S. Treasury bonds to the value of the spot U.S. dollar exchange rate. We show that the foreign convenience yield can be measured by the wedge between the yield on foreign government bonds and the currency-hedged yield on U.S. Treasury bonds (the “Treasury basis”). Even before the 2007-2009 financial crisis, the Treasury basis is negative and occasionally large. Consistent with the theory, an increase in the convenience yield that foreign investors impute to U.S. Treasurys coincides with an immediate appreciation of the dollar, but predicts future depreciation of the dollar. The Treasury basis variation accounts for up to 23% of the quarterly variation in the dollar between 1988 and 2017.

Keywords: Covered Interest Rate Parity, exchange rates, safe asset demand, convenience yields.

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During episodes of global financial instability, there is a flight to the safety of U.S. Treasury bonds which increases their convenience yield, the non-pecuniary value that investors impute to the safety and liquidity properties of U.S. Treasury bonds (see Krishnamurthy and Vissing-Jorgensen, 2012, for example). Figure 1 illustrates this pattern for the 2008 financial crisis. The blue line is the spread between 12-month USD LIBOR and 12-month U.S. Treasury bond yields (TED spread), which is a measure of the convenience yield on U.S. Treasury bonds. The spread roughly triples in the flight to safety of the fall of 2008. We also graph the U.S. dollar exchange rate (green), measured against a basket of other currencies as well as the U.S. dollar currency basis (red), which we will define shortly. The dollar appreciates by about 30% over this period. The hypothesis of this paper is that the increase in the convenience yield on U.S. Treasury bonds assigned by foreign investors will also be reflected in an appreciation of the U.S. dollar. The spot exchange rate of a safe asset currency will reflect the value of all future convenience yields.

![Figure 1: TED Spread, Average Treasury Basis and Dollar.](image)

Our theory rests on the premise that U.S. Treasury bonds are an international safe asset and that investors pay a premium to own these assets. There is a growing body of literature in support of this premise and the key role of the U.S. as the world’s safe asset supplier (see
Caballero, Farhi and Gourinchas, 2008; Caballero and Krishnamurthy, 2009; Maggiori, 2017; He, Krishnamurthy and Milbradt, 2017; Gopinath and Stein, 2017). Our paper develops a theory that connects the U.S. dollar exchange rate to the convenience yields on U.S. Treasurys. We then provide systematic evidence, beyond Figure 1, in support of the theory. We show that our Treasury-based measure of CIP deviations, the Treasury basis, behaves differently from the Libor basis that is studied by Ivashina, Scharfstein and Stein (2015) during the Eurozone crisis, and Du, Tepper and Verdelhan (2017) in their recent influential paper dissecting the breakdown in the LIBOR CIP condition post-crisis.¹

There is a growing body of evidence that some government debt, and particularly U.S. government debt, offers liquidity and safety services to investors. In return, these investors except a lower equilibrium return (Krishnamurthy and Vissing-Jorgensen, 2012; Greenwood, Hanson and Stein, 2015, see). Our paper explores the implications of foreign investors imputing a higher convenience yield to U.S. Treasurys than U.S. investors. Then, in equilibrium, foreign investors should receive a lower return in their own currencies on holding U.S. debt than U.S. investors. Accordingly, the dollar has to appreciate today, providing an expected depreciation, and thus delivering a lower expected return on the U.S. Treasurys to foreign investors than U.S. investors. Thus, our theory predicts that when foreign investors increase their valuation of convenience properties of a given country’s debt, the country’s exchange rate will appreciate. We derive a novel expression for the exchange rate as the expected value of all future interest rate differences and convenience yields less the value of all future currency risk premia, extending the work by Froot and Ramadorai (2005); Engel and West (2005).

To test the theory, we need a measure of the foreign convenience yield. If foreigners also derive utility from a hedged position in U.S. Treasurys, then covered interest parity fails for U.S. Treasurys, because the foreign investor strictly prefers the hedged position in U.S. Treasurys to position in foreign Treasurys. Capital controls or other frictions may prevent the covered interest parity arbitrage, as notably in the recent work of Gabaix and Maggiori (2015), Schmitt-Grohé and Uribe (2016), Farhi and Werning (2017), Amador et al. (2017), and Itskhoki and Mukhin

¹Amador et al. (2017a) attribute CIP deviations to exchange rate management by central banks at the zero lower bound.
Our paper simply points out that covered interest rate parity cannot hold for Treasurys when bonds produce different convenience yields, even in the absence of frictions. The dollar Treasury basis, the wedge between the yield on foreign government bonds and the currency-hedged yield on U.S. Treasury bonds, is a direct measure of the foreign convenience yield on a currency-hedged long position in U.S. Treasurys. We assume that the convenience yield foreign investors derive from an unhedged position in Treasurys is proportional to the dollar basis.

Armed with a measure of the foreign convenience yield on U.S. Treasurys, we take our theory to the data. We use two datasets, a cross-country panel beginning in 1988 and going to 2017 and a US/UK time series that starts in 1970 and ends in 2017. The theory finds strong support in both datasets. Innovations in the dollar basis account for between 13% to 40% of the variation in the spot dollar exchange rate with the right sign: a decrease in the dollar basis coincides with an appreciation of the dollar. These numbers are high in light of the well-known exchange rate disconnect puzzle (Froot and Rogoff, 1995; Frankel and Rose, 1995).

Using a Vector Autoregression to model the joint dynamics of the dollar basis, the interest rate difference and the exchange rate, we find that a 10 basis point rise in the basis drives a 1.5% depreciation in the exchange rate over the next quarter. Then, there is a gradual reversal over the next two to three years as the high basis leads to a positive excess return on owning the US dollar.

Conceptually, our paper is most closely related to Valchev (2016) who shows that the quantity of U.S. Treasury bonds outstanding helps to explain the return on the dollar. Valchev (2016) builds an open-economy model to relate the quantity of US Treasury bonds to the convenience yield on Treasury bonds and the failure of uncovered interest parity. We show that the existence of a foreign convenience yield for US Treasury bonds causes both uncovered interest parity and covered interest parity to fail. We moreover show that variation in the convenience yields as measured by the dollar basis explains a sizeable portion of the variation in the dollar exchange rate.

At a broad level, our theory and evidence is related to portfolio balance models of exchange rate determination such as Kouri (1976) and, more recently, Gabaix and Maggiori (2015), but
our paper is more specific than the portfolio balance model: we argue that the demand for safe
U.S. assets, not just any U.S. assets, drives the dollar exchange rate. The evidence also sheds
light on the exchange rate disconnect puzzle. Convenience yields enter as wedge into the foreign
investors’ Euler equation and the uncovered interest parity condition. Adopting a preference-free
approach, Lustig and Verdelhan (2016) demonstrate that a large class of incomplete markets
models without these wedges cannot simultaneously address the U.I.P. violations, the exchange
rate disconnect and the exchange rate volatility puzzles, while Itskhoki and Mukhin (2017) argue
that models with such a wedge are one way to solve the exchange rate disconnect puzzle.

The paper proceeds as follows. The next section lay out the convenience yield theory. Section
2 take the theory to data. Section 3 further discusses the empirical and theoretical results. The
appendix details our data sources.

1 A Theory of Spot Exchange Rates, Forward Exchange Rates
and Convenience Yields on Bonds

There are two countries, foreign (∗) and the U.S. ($), each with its own currency. Denote
$S_t$ as the nominal exchange rate between these countries, where $S_t$ is expressed in units of
foreign currency per dollar so that an increase in $S_t$ corresponds to an appreciation of the U.S.
dollar. There are domestic (foreign) nominal government bonds denominated in dollars (foreign
currency). We derive bond and exchange rate pricing conditions that must be satisfied in asset
market equilibrium.

1.1 Convenience yields and exchange rates

Denote $y_t^∗$ as the yield on a one-period risk-free zero-coupon bond in foreign currency. Likewise,
denote $y_t^\$ as the yield on a one-period risk-free zero-coupon bond in dollars. The stochastic
discount factor (SDF) of the foreign investor is denoted $M_t^∗$, while that of the US investor is
denoted $M_t^\$. 

Foreign investors price foreign bonds denominated in foreign currency, and the foreign in-
investor’s Euler equation is given by:

$$E_t \left( M_t^* e^{y_t^*} \right) = 1$$

(1)

Foreign investors can also invest in U.S. Treasurys. To do so, they convert local currency to U.S. dollars to receive \( \frac{1}{S_t} \) dollars, invest in U.S. Treasurys, and then convert the proceeds back to local currency at date \( t + 1 \) at \( S_{t+1} \). Then,

$$E_t \left( M_t^* \frac{S_{t+1}}{S_t} e^{y_t^*} \right) = e^{-\lambda_t^*}, \quad \lambda_t^* \geq 0.$$  

(2)

The expression on the left side of the equation is standard. On the right side, we allow investors in U.S. Treasurys to derive a convenience yield, \( \lambda_t^* \), on their Treasury bond holdings. If the convenience yield rises, lowering the right side of the equation, the required return on the investment in U.S. Treasury bonds (the left side of the equation) falls; either the expected rate of dollar depreciation declines or the yield \( y_t^s \) declines, or both.

Next, we use these pricing conditions to derive an expression linking the exchange rate and the convenience yield. We assume that \( m_t^* = \log M_t^* \) and \( \Delta s_{t+1} = \log \frac{S_{t+1}}{S_t} \) are conditionally normal. Then, (1) can be rewritten as,

$$E_t (m_t^*) + \frac{1}{2} Var_t (m_t^*) + y_t^* = 0,$$

(3)

and (2) as,

$$E_t (m_t^*) + \frac{1}{2} Var_t (m_t^*) + E_t[\Delta s_{t+1}] + \frac{1}{2} var_t[\Delta s_{t+1}] + y_t^s + \lambda_t^* - RP_t^* = 0.$$  

(4)

Here \( RP_t^* = -cov_t (m_t^*, \Delta s_{t+1}) \) is the risk premium the foreign investor requires for the exchange rate risk when investing in US bonds.

We combine these two expressions to find that the expected return on foreign currency in levels is given by:

$$E_t[\Delta s_{t+1}] + \left( y_t^s - y_t^* \right) + \frac{1}{2} var_t[\Delta s_{t+1}] = RP_t^* - \lambda_t^*$$

(5)
The left hand side is the excess return to a foreign investor from investing in the US bond relative to the foreign bond. This is the return on the reverse carry trade (for US yields below foreign yields). On the right hand side, the first term is the familiar sources of carry trade return, namely the conditional risk attached to these trades and a Jensen’s inequality term. The second term is from our theory, reflecting the convenience yield. A positive convenience yield lowers the return on the reverse carry trade, i.e., the return to investing in US Treasury bonds. Even in the absence of priced currency risk, \( R_P^* = 0 \), U.I.P. fails when the convenience yield is greater than zero, as previously pointed out by Valchev (2016).

1.2 U.S. demand for foreign bonds

Since U.S. investors have access to foreign bond markets, there is another pair of Euler equations to consider. An increase in the foreign convenience yield imputed to U.S. Treasurys implies an expected depreciation of the dollar. For a U.S. investor, buying foreign bonds when the dollar is expected to depreciate produces a high carry return.

The U.S. investor’s Euler equation when investing in the foreign bond is:

\[
E_t \left( M^S_t \frac{S_t}{S_{t+1}} e^{y^*_t} \right) = 1. \tag{6}
\]

We also assume that U.S. investors derive a convenience yield when investing in U.S. Treasurys:

\[
E_t \left( M^S_t e^{y^S_t} \right) = e^{-\lambda^S_t}, \quad \lambda^S_t \geq 0. \tag{7}
\]

An increase in the U.S. investor’s convenience yield lowers lower U.S. Treasury bond yields, holding the SDF fixed.

We assume log-normality and rewrite these equations to find and another expression for the carry trade return,

\[
(y^*_t - y^S_t) - E_t[\Delta s_{t+1}] + \frac{1}{2} \text{var}_t[\Delta s_{t+1}] = R_P^S_t - \lambda^S_t. \tag{8}
\]
where, $RP_t^s = -cov_t\left(m_t^s, -\Delta s_{t+1}\right)$ is the risk premium the US investor requires for the exchange rate risk when investing in foreign bonds (i.e. the risk premium attached to the dollar appreciating).

Finally, we combine (5) and (8) to find,

$$\lambda_t^* - \lambda_t^s = RP_t^s + RP_t^* - var_t[\Delta s_{t+1}].$$

(9)

An increase in $\lambda_t^*$ has to be accompanied by a proportional increase in the risk premium U.S. investors ($RP_t^s$) demand on foreign bonds. This is a natural equilibrium outcome given that U.S. investors would increase their exposure to foreign exchange risk via the foreign bond carry trade.\(^2\)

Another way of thinking about the US investor’s carry trade return is to consider frictions in financial intermediation. These are outside the model we have written down, but is worth pursuing as a thought experiment. Suppose that the Euler equations for the US investor in foreign bonds apply to a financial intermediary that is subject to financing frictions as in intermediary asset pricing models. Then, the Lagrange multiplier on this constraint will enter the Euler equation, so that a binding constraint can also restore equilibrium. The evidence from Du, Tepper and Verdelhan (2017) is consistent with this frictional mechanism.

### 1.3 Exchange rates and convenience yields

By forward iteration on eqn. (5), the level of exchange rates can be stated as a function of the interest rate differences, the currency risk premia and the future convenience yields (see Froot and Ramadorai, 2005, for a version without convenience yields).

**Proposition 1.** The level of the exchange can be written as:

$$s_t = E_t \sum_{\tau=0}^{\infty} \lambda_{t+\tau}^* + E_t \sum_{\tau=0}^{\infty} (y_t^s - y_{t+\tau}^*) - E_t \sum_{\tau=0}^{\infty} \left( R P_{t+j}^* - \frac{1}{2} Var_t[\Delta s_{t+j}] \right) + \bar{s}. \quad (10)$$

The term $\bar{s} = E_t[\lim_{j \to \infty} s_{t+j}]$ which is constant under the assumption that the exchange rate

\(^2\)There are some subtleties in this argument when markets are complete which we explain in the appendix.
is stationary.$^3$

The exchange rate level is determined by yield differences and the convenience yields. This is an extension of Froot and Ramadorai (2005)'s expression for the level of exchange rates. The first term involves the sum of expected convenience yields on the U.S. Treasurys. The second term involves the sum of bond yield differences. This expression implies that changes in the expected future convenience yields should drive changes in the dollar exchange rate.

### 1.4 Convenience yields and CIP

Next, consider a currency hedged investment in the U.S. Treasury. Naturally, this investment also produces a convenience yield for foreign investors, denoted $\lambda^{*,\text{hedged}}_t$. The corresponding Euler equation is given by:

$$E_t \left[ M_t \frac{F_t^1}{S_t} e^{y_t^*} \right] = e^{-\lambda^{*,\text{hedged}}_t}, \quad \lambda^{*,\text{hedged}}_t \geq 0,$$

where $F_t^1$ denotes the one-period forward exchange rate, expressed in units of foreign currency per dollar. We combine this equation with (1) to derive the Treasury-based dollar basis:

$$x_t \equiv y_t^* + (f_t^1 - s_t) - y_t^* = -\lambda^{*,\text{hedged}}_t.$$

Here, $x_t$ is the dollar basis, or violation of the C.I.P. condition (see Du, Tepper and Verdelhan, 2017). In a world without foreign convenience yields, the basis is zero, but, when $\lambda^{*,\text{hedged}}_t > 0$, foreign investors accept a lower return on hedged investments in U.S. Treasury bonds than in their home bonds. This drives a wedge between the currency-hedged Treasury yield $y_t^* + (f_t^1 - s_t)$ and the foreign currency yield $y_t^*$ and hence causes a negative Treasury basis, $x_t < 0$.\(^4\)

\(^3\)There is ample support for the proposition that the real exchange rate is stationary. Over the last 30 years, which is our data sample, inflation has been low and not volatile, so that the nominal exchange rate is also plausibly stationary.

\(^4\)This result about the connection between Treasury-based CIP violations and convenience yields was pointed out by Adrien Verdelhan in a discussion at the Macro Finance Society (2017).
1.5 Testing the model with nominal exchange rates

Our key assumption is that the convenience yields on the unhedged and hedged foreign investments in U.S. Treasury bonds are proportional to each other,

$$\frac{\lambda_t^*}{\lambda_t^{*, hedged}} = \phi \Rightarrow \lambda_t^* = \phi \lambda_t^{*, hedged} = -\phi x_t$$

(13)

This assumption allows us to measure the unobservable foreign convenience yield $\lambda_t^*$ and thus test out model.

With this assumption, we arrive at two testable relations of our theory.

**Proposition 2.**

1. The level of the exchange can be written as:

$$s_t = -\phi E_t \sum_{\tau=0}^{\infty} x_{t+\tau} + E_t \sum_{\tau=0}^{\infty} (y_{t+\tau} - y_{t+\tau}^*) - E_t \sum_{\tau=0}^{\infty} \left( RP_{t+j}^* - \frac{1}{2} Var_{t+j}[\Delta s_{t+j}] \right) + \bar{s}.$$  

(14)

2. The expected log excess return to a foreign investor of a long position in Treasury bonds is increasing in the risk premium and the Treasury basis:

$$E_t[\Delta s_{t+1}] + (y_t^* - y_t^*) = RP_t^* - \frac{1}{2} Var_t[\Delta s_{t+1}] + \phi x_t$$

(15)

1.6 Testing the model with real exchange rates

We have derived expressions for the equilibrium nominal exchange rate. These expressions are derived under the condition that the nominal exchange rate is stationary. When inflation rates are high, this assumption is likely violated. We next derive expressions for the real exchange rate, which may be stationary even if inflation rates are high.

Denote the log of the foreign and domestic price levels as $p_t^*$ and $p_t^\$*, respectively. The real exchange rate is,

$$q_t = s_t + p_t^\$* - p_t^*.$$  

(16)
We substitute the real exchange rate expression, (16), into the earlier expressions for nominal exchange rates and rewrite to find:

**Proposition 3.** The level of the real exchange can be written as:

\[
q_t = -\phi E_t \sum_{\tau=0}^{\infty} x_{t+\tau} + E_t \sum_{\tau=0}^{\infty} (r^s_{t+\tau} - r^*_t) - E_t \sum_{\tau=0}^{\infty} \left( RP^*_t + \frac{1}{2} Var_{t+j}[\Delta s_{t+j}] \right) + \bar{q}.
\] (17)

where, \(\bar{q} = E_t[\lim_{j\to\infty} q_{t+j}]\) is constant under the assumption that the real exchange rate is stationary. The terms \(r^s_t\) and \(r^*_t\) are the real interest rates, i.e., \(y^s_t - E_t[\Delta p^s_{t+1}]\) is the real dollar interest rate.

We can also write the expected log excess return to a foreign investor of a long position in Treasury bonds in terms of the real exchange rate:

\[
E_t[\Delta q_{t+1}] + \left( (y^s_t - E_t[\Delta p^s_{t+1}]) \right) = RP^*_t - \frac{1}{2} var_t[\Delta s_{t+1}] + \phi x_t
\]

Note however that the expected change in the real exchange rate is equal to the expected change in the nominal exchange rate minus the difference between US and foreign expected inflation. Then, we can rewrite the LHS, canceling out the expected inflation terms, to equal \(E_t[\Delta s_{t+1}] + (y^s_t - y^*_t)\), to recover the same relation as (15).

Last, we make simplifying assumptions to solve for the exchange rate at time \(t\), \(q_t\), explicitly as a function of the basis at time \(t\), \(x_t\). Assume that,

\[
x_t = \rho^* x_{t-1} + (1 - \rho^*) \bar{x} + \epsilon_t^x, \quad \text{where} \quad 0 < \rho^* < 1.
\]

That is, the basis follows an AR(1) process with long-term mean of \(\bar{x}\). We likewise assume that,

\[
z_t \equiv r^s_t - r^*_t - RP^*_t + \frac{1}{2} var_t[\Delta s_{t+1}]
\]

also follows an AR(1) process with persistence parameter \(\rho^z\) and long-term mean \(\bar{z}\). We then evaluate the sum in (28). For the sum to be well defined \(\phi\bar{x}\) must equal \(\bar{z}\). Within a fully
specified model, such a relation can be ensured by central bank behavior that targets a real exchange rate (see the examples in Engel and West (2005)). Then, the real exchange is,

$$q_t = -\phi \frac{x_t}{1 - \rho^x} + \frac{z_t}{1 - \rho^z} + \bar{q}.$$  \hspace{1cm} (18)

2 Empirical Analysis of Exchange Rates, Treasury Basis, and Convenience Yields

2.1 Data

We use two datasets, a panel from 1988 to 2017 and a longer single time series from 1970 to 2016 for the United States/United Kingdom pair.

The shorter panel is based on quarterly data from 10 developed economies. The countries are Australia, Canada, Germany, Japan, New Zealand, Norway, Sweden, Switzerland, United States, and United Kingdom. The sample starts in 1988Q1 and ends in 2017Q2. However, the panel is unbalanced, with data for only a few countries at the start of the sample. The data comprises the bilateral exchange rates with respect to the U.S. dollar, 12-month bilateral forward foreign exchange contract prices, and 12-month government bond yields and LIBOR rates in all countries. We use actual rather than fitted yields for government bonds whenever possible. The main exception is the 2001:9-2008:5 period when the U.S. stopped issuing 12-month bills.\textsuperscript{5}

We construct the basis for each currency following (12). We do so using both government bond yields as measures of $y_t$ as well as LIBOR rates as measures ($x_t^{Treasury}$ and $x_t^{LIBOR}$). In each quarter, we construct the mean and median basis across the panel of countries for that quarter. Figure 2 plots these series.

The blue thick-dashed line corresponds to the median LIBOR basis.$^{6}$ That basis is close to zero for most of the sample and turns negative and volatile beginning in 2007. These facts concerning the LIBOR basis are known from the work of Du, Tepper and Verdelhan (2017). The $\textsuperscript{5}$See Table 7 in the Appendix for detailed information. The Data Appendix contains information about data sources.

$\textsuperscript{6}$The dotted blue-line is the mean LIBOR basis. This series is not informative pre-crisis because its spikes are driven by idiosyncrasies of LIBOR rates in Sweden in 1992 and Japan in 1995.
solid black line is the mean Treasury basis and the dashed black line is the median Treasury basis. Unlike the LIBOR basis, the Treasury basis has always been negative and volatile. The standard deviation of the mean Treasury basis is 24 bps per quarter.

Our second dataset covers the US/UK cross. This data begins in 1970Q1 and ends in 2016Q2. The daily data quality is poor, with many missing values and implausible spikes in the constructed basis from one day to the next. To overcome these measurement issues, we take the average of the available data for a given quarter as the observation for that quarter. We construct the Treasury basis in the same manner as described earlier. Figure 3 plots the resulting series. LIBOR rates do not exist back to 1971. For comparison the figure also plots the mean basis from the cross-country panel. The two series track each other closely for the period where they overlap, but the US/UK basis is consistently higher than the panel basis.
This may indicate that UK bonds also have a convenience yield. Additionally, the basis is above zero for frequently in the early part of the sample. It is relatively easy to alter the model to accommodate convenience yields on both bonds; the equilibrium relations will then depend on the difference in convenience yields, reflected both in the constructed Treasury basis and the exchange rate. That is, such a model will result in the same equilibrium relation between $x$ and the exchange rate as we have derived.

![Figure 3: US/UK Treasury basis from 1970Q1 to 2017Q2 and the mean Treasury basis across the panel of countries, in basis points. The maturity is one year.](image)

2.2 Treasury Basis and the Dollar

We denote the cross-sectional mean basis in the panel as $\bar{x}_t^{Treas}$. Similarly, we use $\bar{y}_t^* - \bar{y}_t^来说 denote the cross-sectional average of yield differences, and $\bar{s}_t$ denotes the equally weighted cross-sectional average of the log of bilateral exchange rates against the dollar. For each of these cross-sectional averages, we employ the same set of countries that are in the sample at time $t$. The average Treasury basis is negatively correlated ($-0.27$) with the average interest rate.
difference $y_t^* - y_t^\$$. We construct quarterly innovations in the basis by regressing $\pi_t^{\text{Treas}} - \pi_{t-1}^{\text{Treas}}$ on $\pi_{t-1}^{\text{Treas}}, \pi_{t-2}^{\text{Treas}}$ and $y_{t-1}^* - y_{t-1}^\$ and computing the residual, $\Delta \pi_t^{\text{Treas}}$. We then regress this innovation on the contemporaneous quarterly change in the spot exchange rate, $\Delta s_t \equiv s_t - s_{t-1}$, Table 1 reports the results. From columns (1), (3), (4), and (6), we see that the innovation in the Treasury basis strongly correlates with changes in the exchange rate. The sign is negative as expected. The result is also stable across the pre-crisis and post-crisis sample. From column (1), we see that a 10 bps decrease in the basis (or an increase in the foreign convenience yield) above its mean coincides with a 0.97% appreciation of the U.S. dollar.

To provide a further sense of magnitudes, note that the basis is mean reverting with an AR(1) coefficient of 0.53. A 10 basis point increase in the basis today implies that next quarter’s basis will be about 5 basis points, and the following quarter will be 2.5 basis points, etc. Substituting these numbers into (14) and dividing by 4 to convert to quarterly values, the sum of these future increases is $\frac{10}{4} \times \frac{1}{1 - 0.53} = 5.3$. From 14, to rationalize the 0.97% appreciation we need a value of $\phi$ of $\frac{0.97}{5.3} = 18.2$. The basis is evidently very sensitive to changes in foreign investors’ convenience valuation of US Treasury bonds.

The $R^2$s are quite high for exchanges rates, i.e. in light of the well-known exchange rate disconnect puzzle (Froot and Rogoff, 1995; Frankel and Rose, 1995). Our regressors account for 16.6% to 23.3% of the variation in the dollar’s rate of appreciation. The LIBOR basis has explanatory power in the post-crisis sample as has been documented in prior work by Avdjiev et al. (2016). They attribute this effect to an increase in the supply of dollars after a dollar depreciation by a foreign banking sector that borrows heavily in dollars. However, in the full sample and the pre-crisis sample there is no relation between the LIBOR basis and the appreciation of the dollar. Even in the post-crisis sample, the Treasury basis doubles the explanatory power. We return to discuss the differential behavior of the LIBOR and Treasury basis in Section 3.2.

Column (3) of Table 1 includes the contemporaneous and the lagged innovation to the basis. This specification provides the best fit in the table with an $R^2$ of 23.3%. The explanatory
Table 1: Average Treasury Basis and Changes in the USD Spot Exchange Rate

The dependent variable is the quarterly change in the log of the spot USD exchange rate against a basket. The independent variables are the innovation in the average Treasury basis, $\Delta \pi^{Treas}$, as log yield (i.e. 50 basis points is 0.005), the lagged value of the innovation, and the innovation in the LIBOR basis. Data is quarterly. OLS standard errors in parentheses.

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<td>$\Delta \pi^{LIBOR}$</td>
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<tr>
<td>$N$</td>
<td>116</td>
<td>116</td>
<td>116</td>
</tr>
</tbody>
</table>

The power of the lag is somewhat surprising and is certainly not consistent with our model as it indicates that there is a delayed adjustment of the exchange rate to shocks to the basis. On the other hand, time-series momentum has been shown to be a common phenomena in many asset markets, including currency markets (see Moskowitz, Ooi and Pedersen, 2012), although there is no commonly agreed explanation for such phenomena. The existence of momentum also indicates that $\phi$ is higher than the coefficient on the contemporaneous innovation, since a shock to the basis affects exchange rates for two quarters. We will evaluate the full impact via a Vector Autoregression in Section 2.4.

The FX markets in both spot and forward are large and liquid. Nevertheless, one may want to know the extent to which the relation we uncover stems from micro-structure order flow effects as in Evans and Lyons (2002) or Froot and Ramadorai (2005). Our theory does not involve these types of effects, and to test our theory ideally our data would reflect the mid of the bid and ask. Figure 4 presents a scatter plot of the change in the quarterly average log exchange rate against the change in the quarterly average basis. By computing a quarterly average, we average out bid-ask bounce and thus likely measure true mid-market prices. The relation we
Figure 4: Scatter plot of changes in the log exchange rate, averaged over a quarter, against shocks to the quarterly average basis. Data is from 1988Q1 to 2017Q2. In red we plot the fitted regression line. The $R^2$ is 22.6% and the slope coefficient is $-14.5$ with a $t$-statistic of 5.77.

uncover is quite strong in this averaged data (in fact it is stronger than the end-of-quarter data of Table 1). Additionally, we can see from the graph that the variation reflected in the exchange rate is an order of magnitude larger than typical bid-ask spreads. The standard-deviation of exchange rate changes in log points is 0.04, or 4%, which is well above typical bid-ask spreads. The standard-deviation of Treasury basis changes is 0.00134 (13.4 basis points). The slope coefficient on the fitted regression line of $-14.5$ implies that a one standard deviation change in the basis drives a 0.45% move in the exchange rate, which is also an order of magnitude larger than bid-ask spreads. Our results evidently are not driven by micro-structure effects.

We next turn to the US/UK data. The sample is longer, going back to 1970Q1. Figure 5 plots the real exchange rate in units of GBP-per-USD in red against the US/UK Treasury basis in blue. Both series are based on quarterly averaged data. We use the real exchange rate here because there are clear trends in the price levels of both countries in the 1970s and early 1980s that we would expect to enter exchange rate determination. It is evident that the two series are negatively correlated. Table 2 presents regressions analogous to that of Table 1. We again see
Figure 5: One-year maturity Treasury basis from 1970Q1 to 2017Q2 for US/UK, in basis points, and the real US/UK exchange rate.

a strong relation between shocks to the basis and exchange rate changes. The relation becomes stronger later in the sample. We think this is in part because of measurement issues with the basis during the 1970s. Note the spikey behavior of the basis in the 1970s in Figure 5. In the sample from 1990 onwards, the regression $R^2$ is 40.7% which is a remarkably strong fit. The coefficients using the full sample are smaller than that of Table 1. For column (3), where the sample starts in 1990, the coefficient of 15.8 is similar in magnitude to our earlier estimates. The coefficient in column (2) of the Table indicates that a 10 basis point increase in the basis is correlated with an 0.42% depreciation in the US dollar against the pound.

2.3 Future currency returns and the Treasury Basis

We turn to the second implication of Proposition 2, which can be read as a forecasting regression. A more negative $x_t$ (high $\lambda_t^*$) today means that today’s exchange rate appreciates, which induces an expected depreciation over the next period.

Note that the LHS of equation (15) is akin to the return on the reverse currency carry trade.
Table 2: US/UK Treasury Basis and Changes in the Spot Exchange Rate

The dependent variable is the quarterly change in the quarterly-mean of the log of the spot USD/UK exchange rate (quoted in GBP-per-USD). The independent variables are the innovation in the quarterly average Treasury basis, $\Delta \pi^{Treas}$, as log yield (i.e. 50 basis points is 0.005) and the lagged value of the innovation. Data is quarterly. OLS standard errors in parentheses.

<table>
<thead>
<tr>
<th></th>
<th>1970Q1 - 2016Q2</th>
<th>1980Q1 - 2016Q2</th>
<th>1990Q1 - 2016Q2</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\Delta \pi^{Treas}$</td>
<td>$-1.82^{**}$</td>
<td>$-4.20^{***}$</td>
<td>$-15.80^{***}$</td>
</tr>
<tr>
<td>Lag $\Delta \pi^{Treas}$</td>
<td>0.78</td>
<td>1.63</td>
<td>2.30</td>
</tr>
<tr>
<td>$R^2$</td>
<td>5.9%</td>
<td>11.8</td>
<td>40.7</td>
</tr>
<tr>
<td>$N$</td>
<td>183</td>
<td>145</td>
<td>105</td>
</tr>
</tbody>
</table>

It involves going long the U.S. Treasury bond, funded by borrowing at the rate of the foreign government bond. The carry trade return has a risk premium, and following the literature, a proxy for this risk premium is the yield differential across the countries, $y^s - \bar{y}^s$. Thus we include the mean yield differential at each date as a control in our regression. Additionally as we have shown in Table 1, there is a slow adjustment to basis shocks, as given by the lag of $\Delta \pi^{Treas}_t$, which we also include in our regression. Our regression specification is,

$$(s_{t+1} - s_t) + (y^s_t - \bar{y}^s_t) = \alpha + \beta_x \pi^{Treas}_t + \beta_y (y^s_t - \bar{y}^s) + \beta_L \Delta \pi^{Treas}_{t-1} + \epsilon_{t+1}$$

Our theory suggests that the coefficient $\beta_x$ should be positive. We run this regression using quarterly data, but compute the returns on the LHS as 3-months, one-year, two-year, and three-year returns. Because there is overlap in the observations, we compute heteroskedasticity and autocorrelation adjusted standard errors.

Table 3 presents the results. The first column reports results for the excess return over the next 3 months. Over this period we see that the coefficient on the basis is negative and statistically significant, in contrast to our theory. But there is a simple reason for this failure: we have seen earlier that there is momentum for one-quarter in the exchange rate. When the basis
Table 3: Predicting Currency Excess Returns in the Panel

The dependent variable is the annualized excess return on a long position in U.S. Treasuries and a short position (equal-weighted) in all foreign bonds, $(\bar{s}_{t+1} - \bar{s}_t) + (y^S_t - \bar{y}^*), in units of log yield (i.e., 5% is 0.05). The independent variables are the average Treasury basis, $\bar{x}^{Treas}$, as log yield (i.e. 50 basis points is 0.005), the lagged value of the innovation in the average Treasury basis, and the average yield difference $(y^S - \bar{y}^*)$ in units of log yield. Data is quarterly from 1988Q1 to 2017Q2. Heteroskedasticity and autocorrelation adjusted standard errors in parentheses.

<table>
<thead>
<tr>
<th></th>
<th>3-month</th>
<th>1-year</th>
<th>2-year</th>
<th>3-year</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\bar{x}^{Treas}$</td>
<td>-25.58***</td>
<td>6.55</td>
<td>11.89***</td>
<td>15.36***</td>
</tr>
<tr>
<td></td>
<td>(10.30)</td>
<td>(7.84)</td>
<td>(4.38)</td>
<td>(3.29)</td>
</tr>
<tr>
<td>$y^S - \bar{y}^*$</td>
<td>0.14</td>
<td>0.49</td>
<td>0.68**</td>
<td>0.85***</td>
</tr>
<tr>
<td></td>
<td>(1.54)</td>
<td>(0.61)</td>
<td>(0.34)</td>
<td>(0.23)</td>
</tr>
<tr>
<td>Lag $\Delta x^{Treas}$</td>
<td>-15.0</td>
<td>-14.6***</td>
<td>-15.46***</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(8.88)</td>
<td>(4.88)</td>
<td>(3.70)</td>
<td></td>
</tr>
<tr>
<td>$R^2$</td>
<td>10.4%</td>
<td>4.2</td>
<td>5.7</td>
<td>13.5</td>
</tr>
<tr>
<td>$N$</td>
<td>113</td>
<td>112</td>
<td>108</td>
<td>104</td>
</tr>
</tbody>
</table>

rises, the currency depreciates immediately, and continues to depreciate for another quarter, giving the negative relation between the basis and the one-quarter currency return. The next three columns consider longer horizons and include the lagged innovation in the basis to control for the momentum effect. The coefficient on $\bar{x}^{Treas}$ for these regressions is positive as suggested by our theory, with $\beta_x$ significantly different from zero in the 2- and 3-year specification. Note that even the known predictor of carry trade returns, $y^S - \bar{y}^*$, is only significant at the longer horizons. Our returns specification suffers from a problem of power. Last, we note that if we exclude the Treasury currency basis variables from the 3-year specification, the $R^2$ drops to 6%.

This evidence suggests that convenience yields may partly account for the profitability of the dollar carry trade (Lustig, Roussanov and Verdelhan, 2014), which goes long in a basket of foreign currencies and shorts the dollar when the average interest rate difference increases, and the Treasury basis widens.

The magnitude of $\beta_x$ is about 10 times larger than the magnitude of $\beta_y$, indicating that the basis, although small, has a sizable effect on exchange rates. If we focus on the 2-year horizon, a 10 bps. widening of the basis (i.e. the basis turns more negative) reduces the expected excess
return on a long position in U.S. bonds by 1.2% per annum over the next three years.

From equation (8) we see that the value of $\phi$ is equal to $\beta_x$ for the 1-year horizon. But the $\beta_x$ for 1-year is small and imprecisely estimated, likely because of the momentum effect we have found. A lower bound for $\phi$ is the estimate of $\beta_x$ on the 2- and 3-year horizon regressions. This is a lower bound because a shock to the basis gradually reverses over time (we explore this formally in the next section), so that the returns in the 2nd and 3rd year are responding to a smaller value of the basis. This gives a lower bound for estimates of $\phi$ from 11.89 to 15.36. Our earlier estimate based on the coefficient in column (1) of Table 3 gave a value of 18.2, indicating consistency in these results.

### Table 4: Predicting Currency Excess Returns in the US/UK Data

The dependent variable is the annualized excess return on a long position in US Treasuries and a short position in the UK Treasury bond, $(s_{t+1} - s_t) + (y^S_t - y^*_t)$, in units of log yield (i.e., 5% is 0.05). The independent variables are the Treasury basis, $x^{Treas}$, as log yield (i.e. 50 basis points is 0.005), the lagged value of the innovation in the Treasury basis, and the yield difference $(y^S_t - y^*_t)$ in units of log yield. Data is quarterly from 1970Q1 to 2016Q2. Heteroskedasticity and autocorrelation adjusted standard errors in parentheses.

<table>
<thead>
<tr>
<th></th>
<th>3-month</th>
<th>1-year</th>
<th>2-year</th>
<th>3-year</th>
</tr>
</thead>
<tbody>
<tr>
<td>$x^{Treas}$</td>
<td>-5.85***</td>
<td>2.17</td>
<td>7.22***</td>
<td>11.92***</td>
</tr>
<tr>
<td></td>
<td>(2.43)</td>
<td>(3.23)</td>
<td>(2.52)</td>
<td>(1.89)</td>
</tr>
<tr>
<td>$y^S_t - y^*_t$</td>
<td>2.44**</td>
<td>1.87***</td>
<td>1.68***</td>
<td>1.74***</td>
</tr>
<tr>
<td></td>
<td>(1.09)</td>
<td>(0.60)</td>
<td>(0.40)</td>
<td>(0.40)</td>
</tr>
<tr>
<td>Lag $\Delta x^{Treas}$</td>
<td>-5.97***</td>
<td>-9.23***</td>
<td>-11.31***</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(3.53)</td>
<td>(3.32)</td>
<td>(2.45)</td>
<td></td>
</tr>
<tr>
<td>$R^2$</td>
<td>7.5%</td>
<td>8.1</td>
<td>11.1</td>
<td>24.6</td>
</tr>
<tr>
<td>N</td>
<td>183</td>
<td>180</td>
<td>176</td>
<td>172</td>
</tr>
</tbody>
</table>

Table 4 presents regressions for the US/UK data. The results are stronger but otherwise broadly in line with those reported in Table 3. The first column shows the momentum effect for the first quarter whereby a high basis drives currency depreciation. As we extend the horizon, the coefficient on the basis turn positive as suggested by theory and become statistically different from zero. The magnitudes are also in line with those reported in Table 3.
2.4 Dynamics of the Basis and the Exchange Rate

We use a Vector Autoregression to get a better sense of the joint dynamics of the interest rate difference, the exchange rate and the Treasury basis. We estimate the VAR separately in both the panel and the US/UK data.

For the panel, we run a VAR with three variables, $\pi_t^{Treas}$, $y_t^g - y_t^r$, and $\pi_t$. The VAR includes one lag of all variables. This specification assumes that the log of the nominal dollar index is stationary, which seems to be case in this sample period. We order the VAR so that shocks to the basis affect all variables contemporaneously, shocks to the exchange rate affect the exchange rate and the interest rate differential but not the basis, and shocks to the interest rate differential only affect itself. The results are not sensitive to switching the order of the exchange rate and interest rate differential. Figure 6 plots the impulse response from orthogonalized shocks to the basis. The left panel plots the dynamic behavior of the basis (in units of percentage points), the middle panel plots the dynamic behavior of the exchange rate (in percentage points), and the right panel plots the behavior of the interest rate differential (in percentage points). The pattern in the figure is consistent with the regression evidence from the Tables. An increase in the basis of 0.2% (decrease in the convenience yield) depreciates the exchange rate contemporaneously by about 3% over two quarters. The finding that the depreciation persists over 2 quarters is consistent with the time-series momentum effect discussed earlier. Then there is a gradual reversal out two to three years over which the effect on the level of the dollar gradually dissipates. There is no statistically discernible effect of the basis on the interest rate differential.

Figure 7 plots the impulse response functions for the US/UK longer series. The variables included are the basis, the interest rate differential and the log of the real exchange rate (GBP-per-USD). For the longer series, it is apparent that it is better to assume that the log of the real exchange rate is stationary given trends in relative price levels in the US and UK in the high inflation period of the 1970s and early 1980s. The impulse response patterns in this figure are similar to Figure 6 but have smaller magnitudes. An increase in the the basis of 40 basis points leads to a depreciation in the dollar of about 2% over two quarters. Then, the effect gradually reverses out over 2 to 3 years.
Figure 6: The red line plots the impulse response of an orthogonalized shock to the average Treasury basis to the basis (left panel), the log nominal spot exchange rate (middle panel), and interest rate differential (right panel). The units for the y-axis are in percentage points. The grey areas indicates 95% confidence intervals. The VAR is estimated using a sample from 1988Q1 to 2017Q2.
Figure 7: The red line plots the impulse response of an orthogonalized shock to the US/UK Treasury basis to the basis (left panel), the log real GBP-per-USD spot exchange rate (middle panel), and US/UK interest rate differential (right panel). The units for the $y$-axis are in percentage points. The grey areas indicate 95% confidence intervals. The VAR is estimated using a sample from 1970Q1 to 2016Q2.
2.5 News decomposition

We denote $d_t = y_t^{US} - y_t^{UK}$. Define $z'_t = \begin{bmatrix} x_t & d_t & s_t \end{bmatrix}$. We estimate following the first-order VAR for $z_t$:

$$z_t = \Gamma_0 + \Gamma_1 z_{t-1} + \alpha_t,$$

where $\Gamma_0$ is a 3-dimensional vector, $\Gamma_1$ is a $3 \times 3$ matrix and $\alpha_t$ is a sequence of white noise random vector with mean zero and variance covariance matrix $\Sigma$. The variance covariance matrix is required to be positive definite.

The log of the currency excess return is given by $r_t = s_t - s_{t-1} + d_{t-1} - 1 + i_{t-1}$. The realized risk premium component of the log currency excess return is the realized log excess return minus the convenience yield: $r_{pt} = r_t - \phi x_{t-1}$. As a result, we can add an equation for the risk premium component of the log excess return to the VAR, and we end up with the following first-order VAR:

$$\begin{bmatrix} r_{pt} \\ x_t \\ d_t \\ s_t \end{bmatrix} = \begin{bmatrix} \gamma_0 \\ \Gamma_{0,1} \\ \Gamma_{0,2} \end{bmatrix} + \begin{bmatrix} 0 & \Gamma_{3,1} & \Gamma_{3,2} + 1 & \Gamma_{3,3} - 1 \\ 0 & \Gamma_{1,1} & \Gamma_{1,2} & \Gamma_{1,3} \\ 0 & \Gamma_{2,1} & \Gamma_{2,2} & \Gamma_{2,3} \end{bmatrix} \begin{bmatrix} r_{pt-1} \\ x_{t-1} \\ d_{t-1} \\ s_{t-1} \end{bmatrix} + \begin{bmatrix} a_{3,t} \\ a_{1,t} \\ a_{2,t} \\ a_{3,t} \end{bmatrix} \tag{19}$$

When we use the real exchange rate $q_t$, we replace the interest rate difference $d_t$ with the real interest rate difference $i_{t-1} = d_{t-1} - \pi_t^{US} + \pi_t^{UK}$. The log of the currency excess return is then $r_t = q_t - q_{t-1} + i_{t-1} = s_t - s_{t-1} + d_{t-1}$; the realized inflation difference drops out from the excess return.

Accordingly, we can define the state as the vector of demeaned variables: $y'_t = \begin{bmatrix} \tilde{r}_{pt} & \tilde{x}_t & \tilde{d}_t & \tilde{s}_t \end{bmatrix}$. $y_t$ is a VAR process of order 1

$$y_t = \Psi_1 y_{t-1} + u_t,$$

where $\Psi_1$ is the $4 \times 4$ matrix defined in (19) and $u_t$ is the $4 \times 1$ vector of residuals defined above.

Our analysis follows Froot and Ramadorai (2005). From equation (17), changes in the exchange rate are due to changes in expectations of the basis ("convenience yield news"), changes
in expectation of interest rate differentials ("cash flow news"), and changes in expectation of risk premiums ("discount rate news"). We decompose exchange rate movements into those components and estimate how much each of the components account for variation in the exchange rate.

\[ s_t = -\phi E_t \sum_{\tau=0}^{\infty} x_{t+\tau} + E_t \sum_{\tau=0}^{\infty} (y_{t+\tau}^s - y_{t+\tau}^s) - E_t \sum_{\tau=0}^{\infty} \left( RP_{t+\tau}^s - \frac{1}{2} Var_{t+\tau}[\Delta s_{t+\tau+1}] \right) + \bar{s}. \] (20)

We assume homoskedasticity of exchange rate changes. As a result, the expression for the log of the exchange rate is given by:

\[ s_t = -\phi E_t \sum_{\tau=0}^{\infty} x_{t+\tau} + E_t \sum_{\tau=0}^{\infty} d_{t+\tau} - E_t \sum_{\tau=1}^{\infty} r p_{t+\tau} + \bar{s}. \] (21)

Using the VAR expressions, this simplifies to: \( s_t = -\phi E_t \sum_{\tau=0}^{\infty} x_{t+\tau} + \sum_{j=0}^{\infty} e_3 \Psi_1^j y_{t-j} - \sum_{j=1}^{\infty} e_1 \Psi_1^j y_{t-j} + \bar{s}. \)

**News** From the definition of \( r p_t \), it is easy to check that the current return innovation can be decomposed into a cash flow term, a discount rate term and a convenience yield term:

\((E_t - E_{t-1}) r p_t = (E_t - E_{t-1}) \left[ \sum_{j=0}^{\infty} d_{t+j} \right] + (E_t - E_{t-1}) \left[ \sum_{j=0}^{\infty} \phi x_{t+j} \right] - (E_t - E_{t-1}) \left[ \sum_{j=1}^{\infty} r p_{t+j} \right] \)

First, we compute the discount rate news from the VAR as:

\[ N_{DR,t} = (E_t - E_{t-1}) \left[ \sum_{j=1}^{\infty} r p_{t+j} \right] = e_1' \Psi_1 (I - \Psi_1)^{-1} u_t \]

Second, we can compute the CF or interest rate news from the VAR as:

\[ N_{CF,t} = (E_t - E_{t-1}) \left[ \sum_{j=0}^{\infty} d_{t+j} \right] = e_3' (I - \Psi_1)^{-1} u_t \]

---

7Note that the risk premium is \( RP_t = E_t r p_{t+1} + \frac{1}{2} Var[\Delta s_{t+1}] \). As a result, the discount rate component of the log exchange rate can be stated as: \( E_t \sum_{\tau=0}^{\infty} RP_{t+\tau}^s = E_t \sum_{\tau=1}^{\infty} r p_{t+\tau} + \text{constant} = E_t \sum_{\tau=1}^{\infty} (r x_{t+\tau} - \phi x_{t+\tau-1}) + \text{constant}. \)
Finally, what’s left is the news about the convenience yields, which can be backed out of the discount rate and cash flow news:

\[ N_{CY,t} = (E_t - E_{t-1}) \left( \sum_{j=0}^{\infty} \phi x_{t+j} \right) = -N_{CF,t} + N_{DR,t} + e'_1 u_t \]

Table 5: News Decomposition

<table>
<thead>
<tr>
<th>( \phi )</th>
<th>var(( CY ))</th>
<th>var(( CF ))</th>
<th>var(( DR ))</th>
<th>2cov(( CY, CF ))</th>
<th>2cov(( CY, DR ))</th>
<th>-2cov(( CF, DR ))</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Nominal Exchange Rate</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5.00</td>
<td>0.10</td>
<td>0.10</td>
<td>1.26</td>
<td>0.07</td>
<td>-0.05</td>
<td>-0.48</td>
</tr>
<tr>
<td></td>
<td>0.09</td>
<td>0.06</td>
<td>0.27</td>
<td>0.10</td>
<td>0.20</td>
<td>0.23</td>
</tr>
<tr>
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<tr>
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<td>0.38</td>
<td>0.06</td>
<td>0.43</td>
<td>0.21</td>
<td>0.65</td>
<td>0.27</td>
</tr>
<tr>
<td>15.00</td>
<td>0.93</td>
<td>0.10</td>
<td>1.77</td>
<td>0.20</td>
<td>-1.37</td>
<td>-0.62</td>
</tr>
<tr>
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<td>0.85</td>
<td>0.06</td>
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<td>1.47</td>
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</tr>
<tr>
<td>20.00</td>
<td>1.65</td>
<td>0.10</td>
<td>2.33</td>
<td>0.26</td>
<td>-2.65</td>
<td>-0.68</td>
</tr>
<tr>
<td></td>
<td>1.50</td>
<td>0.06</td>
<td>1.28</td>
<td>0.42</td>
<td>2.68</td>
<td>0.43</td>
</tr>
<tr>
<td><strong>Real Exchange Rate</strong></td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5.00</td>
<td>0.06</td>
<td>0.13</td>
<td>0.82</td>
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<td>-0.06</td>
<td>-0.04</td>
</tr>
<tr>
<td></td>
<td>0.03</td>
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<td>0.21</td>
<td>0.07</td>
<td>0.09</td>
<td>0.13</td>
</tr>
<tr>
<td>10.00</td>
<td>0.25</td>
<td>0.13</td>
<td>0.94</td>
<td>0.17</td>
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<td>-0.13</td>
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<td>0.14</td>
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<td>-0.21</td>
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<td>-1.75</td>
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<tr>
<td></td>
<td>0.49</td>
<td>0.06</td>
<td>0.43</td>
<td>0.28</td>
<td>0.81</td>
<td>0.25</td>
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</tbody>
</table>

The top panel in Table 5 presents the results, estimated from the longest sample we have which is the US/UK nominal exchange rate from 1970 to 2016. We report results for different values of \( \phi \) ranging from 5 to 20. Our estimates based on earlier regressions suggest a value of \( \phi \)
of between 15 and 20. At the $\phi = 15$ case, we see that convenience yield news ($CY$) accounts for 93% of the variance in quarterly exchange rates, in line with the high $R^2$ from earlier regressions. Interest rate news ($CF$) accounts for only a small component (7.2%) of the variance, while risk premium news ($DR$) accounts for a sizable component of 177%. However, the standard errors on our variance estimates are almost as large as the variance estimates themselves. The bottom panel reports results for real exchange rates.

Note that the numbers in each row add up to 100% because shocks to these news components may be negatively correlated, as is apparent from the last two columns of the table. That is, the numbers in Table 5 should be read as the answer to the question: suppose we only had shocks to the basis, holding other components fixed – even though in practice such components will change when a basis shock arrives – how much variance in exchange rates will the basis shocks generate.

3 Discussion

3.1 How does the evidence identify safe-asset demand for the dollar?

We construct the basis from the safest asset, the US Treasury bond, and document a relation between this basis and the dollar. It is evident that in the pre-crisis sample if we construct the basis from LIBOR rates, which reflect a bank deposit asset that is not as safe as Treasury bills, there is no relation between the measured LIBOR basis and the dollar. By extension if we were to construct a basis say from the S&P500, measuring the expected return on the stock market, we expect we will find no relation between the basis and the dollar.

Thus our evidence does not indicate that general flows of capital into US markets drive the value of the dollar, as in a portfolio balance model along the lines of Gabaix and Maggiori (2015). Rather a specific form of the capital flow, that for safe US assets, drives the value of the dollar.
3.2 Why does the LIBOR basis matter only after the crisis?

In US data, Krishnamurthy and Vissing-Jorgensen (2012) observe that there is a convenience yield on both Treasury bonds and other near-riskless private bonds such as bank deposits. They moreover show that some investors view near-riskless private bonds as partial substitutes for Treasury bonds. It is likely that this same property applies to foreign investors and helps explains the behavior of the LIBOR basis, as we argue in this section.

Consider the following adaptation of the model in Krishnamurthy and Vissing-Jorgensen (2012). Suppose foreign investors have preferences:

$$E^{\infty} \sum_{t=1}^{\infty} \beta^t u(C_t), \quad (22)$$

where $C_t$ is the sum of an endowment $c_t$ and convenience benefits:

$$C_t = c_t + \nu_t(\theta^P_t + \theta^B_t) + \mu_t(\theta^B_t).$$

Here $\theta^P_t$ are the market value of holdings of private safe assets and $\theta^B_t$ are the market value of holdings of Treasury bonds. The terms $\nu_t$ and $\mu_t$ are convenience benefits, satisfying $\nu_t, \mu_t > 0, \nu'_t, \mu'_t \geq 0$ and, $\nu''_t, \mu''_t \leq 0$. We make the further assumption that $\nu_t$ has a satiation point $\Theta$ where $\nu'_t(\Theta) = 0$. Private bonds and Treasury bonds are partial substitutes (the $\nu_t$ term), but Treasury bonds offer strictly more convenience benefits than private bonds (the $\mu_t$ term).

The first order condition for investing in a US Treasury bond that pays yield of $y^S_t$ on a hedged basis is,

$$-u'(C_t) + \nu'_t(\theta^P_t + \theta^B_t) + \mu'_t(\theta^B_t) + E_t \left[ \beta u'(C_{t+1}) \frac{F^1_t}{S_t} e^{\gamma_t} \right] = 0$$

Defining $M_t^* = \beta \frac{u'(C_{t+1})}{u'(C_t)}$, we have that,

$$E_t[M_t^*] \frac{F^1_t}{S_t} e^{\gamma_t} = e^{-\lambda_t^*, hedged}$$
where,
\[ e^{-\lambda_t^{*,hedged}} \approx 1 - \lambda_t^{*,hedged} = 1 - \nu_t'(\theta_t^P + \theta_t^B) - \mu_t' \]

Relative to earlier equations (see (11)), we have now expressed the convenience yield in terms of asset quantities.

We follow the same steps for the investment in private bonds (bank deposits). The Euler equation gives (for private bond yield $y_t^{*,P}$),
\[ E_t [M_t^*] \frac{F_t^1}{S_t} e^{y_t^{*,P}} = e^{-\lambda_t^{*,hedged,P}} \]

where,
\[ e^{-\lambda_t^{*,hedged,P}} \approx 1 - \lambda_t^{*,hedged,P} = 1 - \nu_t'(\theta_t^P + \theta_t^B). \]

Note that $\nu_t'$ appears but $\mu_t'$ does not, because the private bonds only offer $\nu$-type convenience benefits. Clearly the convenience yield on the Treasury bond investment is strictly higher than that of the private bond investment since $\nu_t' > 0$.

Next consider an unconstrained US investor ("bank") that also trades in the forward contract, $F_t^1$, as well as bank deposits in the US and foreign country and receives no convenience yield on either deposit. It follows that arbitrage requires,
\[ E_t [M_t^*] \frac{F_t^1}{S_t} e^{y_t^{*,P}} = E_t [M_t^*] e^{y_t^{*,P}}, \]

where $y_t^{*,P}$ and $y_t^{*,P}$ are the bank deposit rates in each country. We can simplify this expression to,
\[ \frac{F_t^1}{S_t} e^{y_t^{*,P}} = e^{y_t^{*,P}}, \]

which is the standard LIBOR-based CIP condition with no convenience yields. We immediately see that CIP must hold when computed using bank LIBOR deposit rates because of the possibility of bank arbitrage.

How can it be that the LIBOR basis is zero and yet foreign investors have convenience demand for US bank deposits? The answer is that in the equilibrium, unconstrained banks
increase supply, $\theta_t^P$, to the point where $\nu_t' = 0$ and hence $\lambda_t^{*,hedge, P} = 0$. But note that even at this large supply, we will have that,

$$\lambda_t^{*,hedge} = \lambda_t^{*,hedge, P} + \mu_t'(\theta_t^P) > 0.$$ 

This latter situation describes the pre-crisis equilibrium. The LIBOR basis is near zero; the Treasury basis is non-zero; and, only the Treasury basis has explanatory power for the dollar. (Following the logic we have provided, the missing arbitrageur here is the US Treasury, which could drive the Treasury basis to zero if it acted like an unconstrained bank.)

In the post-crisis equilibrium, banks are constrained hence both $\lambda_t^{*,hedge, P}$ and $\lambda_t^{*,hedge}$ are positive. Both are correlated with $\lambda_t^*$ and both have explanatory power for the dollar, although as we have shown the Treasury basis has greater explanatory power.

This description of equilibrium relies on two assumptions: constraints on bank arbitrage in the post-crisis period; and, partial substitution between bank deposits and Treasury bonds. Du, Tepper and Verdelhan (2017) present compelling evidence in support of the first assumption. Here we provide support for the first assumption. We show that as foreign private Treasury holdings fall, holdings of US dollar assets which are substitutes for Treasury bonds, in particular bank deposits, rise.\(^8\) We obtain data on foreign holdings of U.S. Treasury bonds back to 1951Q4 from the Flow of Funds of the Federal Reserve. We also obtain data on U.S. assets which may be convenience substitutes.\(^9\) We compute the ratio of this aggregate to US GDP to remove trends. We then correlate the 2-year growth rates in this non-Treasury debt series with the 2-year growth rates of the Treasury debt series, using Q4 to Q4 growth rates, with non-overlapping data. The sample is from 1951Q4 to 2015Q4. Figure 8 presents a scatter plot of the series, which are evidently negatively correlated ($-0.37$). The red line in the figure is the fitted regression line.

The regression coefficient is $-0.85$ with a $t$–statistic of 2.20 and the regression $R^2$ is 14%.

\(^8\)Maggiori, Neiman and Schreger (2017) document that there is a unique world demand for US dollar corporate bonds. When investors hold bonds of other currencies, they largely hold US dollar bonds. We additionally show that the world bond demand is for safe US bonds by documenting that private safe bonds and safe Treasury bonds are portfolio substitutes for foreign investors.

\(^9\)These include Flow of Funds items repos, checkable deposits and currency, time and savings deposits, money market mutual fund shares, corporate and foreign bonds, commercial paper, and agency and GSE-backed securities.
Figure 8: Growth in foreign holdings of Treasury and non-Treasury debt

Scatter plot of the 2-year growth in foreign holdings of US Treasury debt/GDP and non-Treasury US debt holdings/GDP. The sample is from 1951Q4 to 2015Q4. Growth rates are compute as log changes from Q4 to the Q4 2-year hence. Data is non-overlapping. The red line is the fitted regression line.

3.3 Are Japan and Switzerland also identified as safe asset currencies by their basis?

Figure 9 graphs the Treasury basis for four carry-trade countries, Switzerland, Japan, New Zealand, and Australia. We compute these bases in a similar manner as the US, but treating each of the countries as the base country. Additionally, we exclude the US from the computation.

It is readily apparent that the basis of Japan and Switzerland do not behave like the US. The mean basis is 30 basis points for Switzerland and 25 basis points for Japan. That is the bases are positive and not negative as we saw for the US, indicating they their government bonds do not share the safe asset property of the US. Note that it is possible that these currencies are safe-haven currencies, it is just that the metric we are using to identify demand for safe
Figure 9: Treasury Basis for Switzerland, Japan, New Zealand, and Australia

We graph the basis for four countries from 1996Q1 to 2017Q2. The bases are computed as the cross-sectional mean across all countries, excluding the United States.

assets, namely the valuation of investment in the country’s government bond, is not sensitive to safe haven demand. At present, we think the pattern is because Japan and Switzerland are funding currencies in the carry trade, and do not have government bonds where foreign investors especially like to invest. This point becomes clear when we also look at the bases for Australia and New Zealand. The mean basis is -24 basis points for Australia and -27 basis points for New Zealand. Our hypothesis is that these are countries where foreign carry trade investors own government bonds, lowering the basis. We investigate relations between these bases and exchange rates in a companion paper.

3.4 Time-variation in the demand for safe assets

Table 6 provides some statistics on the covariates of the Treasury basis. In the first column, we regress the basis on the OIS-T-bill spread which is a measure of the liquidity premium on
We regress the quarterly average Treasury basis, $\pi^{Treas}$, on a number of US money market spreads and the US to foreign government bond interest rate differential. The spreads and interest rate differential are constructed as the quarterly average of the indicated series. Data is from 1988Q1 to 2017Q2 for the regressions with 118 observations and 2001Q4 to 2017Q2 for the regressions with 63 observations. OLS standard errors in parentheses.

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<td>-0.029***</td>
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<td>82.9</td>
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<td>63</td>
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<td>118</td>
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<td>118</td>
</tr>
</tbody>
</table>

Treasury bonds. Note that the basis is negative on average (see Figure 2). There is little relation between the basis and OIS-Tbill. The second column instead uses the spread between LIBOR and OIS which is a measure of the riskiness of banks. This spread is strongly negatively related to the basis. When the LIBOR-OIS spread rises, the basis goes more negative, as in the crisis episode pictured in Figure 1. The $R^2$ of the regression is 69.5% indicating a flight-to-quality pattern in the foreign demand for safe Treasury bonds. OIS is only available from 2001. Column (3) reports the correlation with the LIBOR-Tbill spread which we can construct to the start of our sample in 1988. There is a strong negative relation between the spread and the basis, and we learn from columns (1) and (2) that the relation is likely due to the LIBOR-OIS component of this spread (note also that the coefficient on LIBOR-OIS is quite similar to the coefficient on LIBOR-T-bill). Column (4) includes the spread between US interest rates and the mean foreign interest rate. When US rates are high relative to foreign rates, the basis is more negative. We have run specifications where we include both US and foreign interest rates, and subject to the
caveat that these rates do move together, the correlation seems to be driven by the US interest rate and not the foreign rate. Column (5) and (6) include both the LIBOR spread and the US to world interest rate differential. The explanatory power for the basis is largely driven by the LIBOR spread as one can see when comparing the $R^2$ in columns (5) and (6) to those in columns (3) and (4).

4 Conclusion

Du, Tepper and Verdelhan (2017) have convincingly argued that Libor-based CIP deviations reflect the effects of frictions recently introduced in the financial intermediation sector, while Ivashina, Scharfstein and Stein (2015) single out European banks who rely on dollar funding and were forced to borrow synthetic dollars during the Eurozone crisis. Our work complements theirs by showing that safe asset demand for U.S. Treasurys can independently drive a wedge between currency-hedged Treasury yields and foreign yields. These wedges have explanatory power for variation in the dollar exchange rate, consistent with the convenience yield theory, even prior to the recent financial crisis. In contrast, the Libor basis covaries with the dollar exchange rate only after the financial crisis (see Avdjiev et al., 2016).
References


A Convenience Yields in Complete Markets

We follow the approach of Backus, Foresi and Telmer (2001). Consider the Euler equations (1) and (6) for the US and foreign investor when investing in the foreign bond. To satisfy these Euler equations, we conjecture an exchange rate process that satisfies,

\[ M_t^f \frac{S_t}{S_{t+1}} = M_t^r. \]

This guess, as can easily be verified, satisfies the Euler equations. If financial markets are complete, then this is the unique exchange rate process that is consistent with the absence of arbitrage opportunities. Using lower case letters to denote logs, and log-linearizing this expression, we find:

\[ \Delta s_{t+1} = m_t^f - m_t^r. \]

(25)
Next consider the pair of Euler equations, (2) and (7), which apply to investments in the US bond that gives a convenience yield. We conjecture an exchange rate process that satisfies,

\[ M_t^e e^{\lambda^*_t} \frac{S_{t+1}}{S_t} = M_t^g e^{\lambda^g_t}. \]

Log-linearizing this expression, we find:

\[ \Delta s_{t+1} = \left( m_t^g - m_t^* \right) + \left( \lambda_t^g - \lambda_t^* \right) \]

It is evident that (25) and (26) cannot both be satisfied in an equilibrium unless \( \lambda_t^* = \lambda_t^g \). But note that in the case, convenience yields have no impact on exchange rates.

How is equilibrium restored when \( \lambda_t^* \neq \lambda_t^g \)? The answer is that one of the Euler equations must be an inequality. There are many ways this may happen. Portfolio choices could be at a corner. For example, if foreign investors assign a positive convenience yield to their own foreign bonds, while US investor do not, then the US investor Euler equation does not apply to foreign bonds. Alternatively, if foreign convenience demand for US bonds is so high that US investors do not own US bonds, then the US Euler equation does not apply to US bonds. Another possibility are forms of market segmentation. Suppose that some US investors derive convenience value from US bonds, but these same investors do not own foreign bonds. Other US investors do not derive convenience value from US bonds, and these investors do own foreign bonds. In these cases as well, one of the Euler equations we have posited is an inequality.

### B Data Appendix

For the FX source, before December 1996, we use the Barclays Bank source from Datastream. After December 1996, we use World Markets Reuters (WMR) from Datastream. The Datastream codes for the spot rates and 12M forward rates are: BBGBPSP, BBGBPYPF, BBAUDSP, BBAUDYF, BBCADSP, BBCADYF, BBDEMSP, BBDEMYF, BBJPYS, BBJFPYF, BNZDSP, BBNZDYS, BBNOYF, BBNOKYF, BBSEKSP, BBSEKYF, BBCHFSP, BBCHFYF, AUSTDOL, UKAUDYF, CNDOLLR, UKCADYF, DMARKER, UKDEMRF, JAPAYEN, UKJPYYF, NZDOLLR, UNKNZDYS, NORNKRON, UKNOKYF, SWEEKRON, UKSEKYF, SWISSFR, UKCHFYF, UKDOLLR, UKUSDYF.

For the Government Bond Yields (see Table 8), most country-maturities pairs only use one source, except if there are gaps. If there are gaps, we use all the data from the first source wherever available, as indicated in the Table, and then fill in any gaps for some year month using the second data source (indicated by ‘2’).

For LIBORs (see Table 9), we use the BBA-ICE LIBOR when available. Coverage is good for Germany, Japan, Switzerland, UK, and U.S.. For other countries, we then use other interbank survey rates (BBSW, CDOR, NIBOR, STIBOR) to fill in any gaps. We then use deposit rates (Bank Bill, NKD, SKD) for any remaining gaps.
Table 7: Country Composition of Unbalanced Panel

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Table 8: Sources for Government Bond Yields

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The numbers indicate which source takes precedence.

Table 9: Sources for LIBOR

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C Vector Autoregression

We use \( d_t = y_t^{US} - y_t^{UK} \). Define \( z'_t = \begin{bmatrix} x_t & d_t & s_t \end{bmatrix} \). A multivariate time series \( z_t \) is a VAR process of order 1

\[
z_t = \Gamma_0 + \Gamma_1 z_{t-1} + a_t
\]

where \( \Phi_0 \) is a \( k \)-dimensional vector, \( \Phi_1 \) is a \( k \times k \) matrix and \( a_t \) is a sequence of white noise random vector with mean zero and variance covariance matrix \( \Sigma \). The variance covariance matrix is required to be positive definite.

Note that \( rx_t = s_t - s_{t-1} + d_{t-1} \). Also note that the actual risk premium component is \( RP_t = rx_t - \phi \times x_{t-1} \).

Define the vector of demeaned variables \( y'_t = \begin{bmatrix} \tilde{r}_t & \tilde{x}_t & \tilde{d}_t & \tilde{s}_t \end{bmatrix} \). \( y_t \) is a VAR process of order 1

\[
y_t = \Psi_t y_{t-1} + u_t,
\]

where \( \Psi_t \) is defined above.

We have shown that the level of the exchange can be written as:

\[
s_t = -\phi E_t \sum_{\tau=0}^{\infty} x_{t+\tau} + E_t \sum_{\tau=0}^{\infty} (y_{t+\tau} - \hat{y}_{t+\tau}) - E_t \sum_{\tau=0}^{\infty} \left( RP^*_{t+\tau} - \frac{1}{2} \text{Var}_{t+\tau} [\Delta s_{t+\tau+1}] \right) + \bar{s}.
\]

We assume heteroskedasticity of exchange rate changes. Note that the risk premium is \( RP_t = E_t rp_{t+1} + \frac{1}{2} \text{Var} [\Delta s_{t+1}] \), which implies that the risk premium term can be stated as:

\[
E_t \sum_{\tau=0}^{\infty} RP^*_{t+\tau} = E_t \sum_{\tau=1}^{\infty} rp_{t+\tau} + \text{constant} = E_t \sum_{\tau=1}^{\infty} (rx_{t+\tau} - \phi x_{t+\tau-1}) + \text{constant}.
\]

This implies that we can state the log of the exchange rate as follows:

\[
s_t = -\phi E_t \sum_{\tau=0}^{\infty} x_{t+\tau} + E_t \sum_{\tau=0}^{\infty} d_{t+\tau} + E_t \sum_{\tau=0}^{\infty} rp_{t+\tau} + \bar{s}.
\]

This also implies that news about exchange rates can be decomposed into a cash flow term, a discount rate term and a convenience yield term:

\[
(E_t - E_{t-1}) rp_t = (E_t - E_{t-1}) \sum_{j=0}^{\infty} d_{t+j} + (E_t - E_{t-1}) \sum_{j=0}^{\infty} \phi x_{t+j} - (E_t - E_{t-1}) \sum_{j=1}^{\infty} rp_{t+j}
\]
We know that computing risk premia can be done by:

\[ E_t r_{t+j+1} = e_1 \Psi_{1+j} y_t \]

We compute the discount rate news as:

\[ N_{DR,t} = (E_t - E_{t-1}) \left[ \sum_{j=1}^{\infty} r_{t+j} \right] = e'_1 \Psi_1 (I - \Psi_1)^{-1} u_t \]

We can compute the CF news as:

\[ N_{CF,t} = (E_t - E_{t-1}) \left[ \sum_{j=0}^{\infty} d_{t+j} \right] = e'_3 (I - \Psi_1)^{-1} u_t \]

Finally, what’s left is the news about the convenience yields:

\[ N_{CY,t} = (E_t - E_{t-1}) \left[ \sum_{j=0}^{\infty} \phi_{x_{t+j}} \right] = -N_{CF,t} + N_{DR,t} + e'_1 u_t \]