Foreign Safe Asset Demand and the Dollar Exchange Rate *

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Abstract

We develop a theory that links the U.S. dollar's valuation in FX markets to foreign investors' demand for U.S. safe assets. When the convenience yield that foreign investors derive from holding U.S. safe assets increases, the U.S. dollar immediately appreciates, thus lowering the foreign investors' expected future return from owning U.S. safe assets. The foreign investors' convenience yield can be inferred from the wedge between the yield on foreign government bonds and the currency-hedged yield on safe U.S. Treasury bonds, which we call the U.S. Treasury basis. Consistent with the theory, we find that a widening of the U.S. Treasury basis coincides with an immediate appreciation and a subsequent depreciation of the U.S. dollar. The Treasury basis accounts for up to 41% of the quarterly variation in the dollar. Our results lend empirical support to recent theories of exchange rate determination which ascribe a special role to the U.S. as a provider of world safe assets.

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 offered by U.S. Treasury bonds (see Krishnamurthy and Vissing-Jorgensen, 2012, for example). Figure 1 illustrates this pattern during 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 during the fall of 2008. We also graph the U.S. dollar exchange rate (black), measured against a basket of other currencies as well as the U.S. Treasury 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 cumulative value of all future convenience yields.

[Figure 1 about here.]

In the post-war era, the U.S. has been the world's most favored supplier of safe assets and investors pay a sizeable premium, the convenience yield, to own these assets. There is a growing literature that seeks to understand why the U.S. is the world's safe asset supplier and how the U.S. position affects the international economic equilibrium (see Gourinchas and Rey, 2007; Caballero, Farhi and Gourinchas, 2008; Caballero and Krishnamurthy, 2009; Maggiori, 2017; He, Krishnamurthy and Milbradt, 2018; Gopinath and Stein, 2017).[1] Our paper develops a theory of the dollar's valuation that imputes a central role to the convenience yields that foreign investors derive from the ownership of U.S. safe assets.

Our paper explores the implications of foreign investors imputing a higher convenience yield to U.S. safe assets, such as U.S. Treasurys, than U.S. investors. This being the case, in equilibrium, foreign investors should receive a lower return in their own currencies on holding U.S. safe assets than U.S. investors. To produce lower expected returns on U.S. safe assets in foreign currency, the dollar has to appreciate today and, going forward, depreciate in expectation to deliver a lower expected return to foreign investors than U.S. investors. We derive a novel expression for the dollar exchange rate as the expected value of all future interest rate differences and

[1] There is a separate literature on the special role of the US dollar and US asset markets in the world economy. See Gourinchas, Rey and Govillot (2011) on the "exorbitant privilege" of the US that drives low rates of return on US dollar assets. In their analysis, the low return stems from the role of the US in international risk sharing. See Lustig, Roussanov and Verdelhan (2014*a*) on evidence for a global dollar factor driving currency returns around the world. See Gopinath (2015) for evidence on the dominant role of the dollar as an invoicing currency.

convenience yields less the value of all future currency risk premia, extending the work by Froot and Ramadorai (2005) and Engel and West (2005). Our theory predicts that a country's exchange rate will appreciate whenever foreign investors increase their valuation of the current and future convenience properties of that country's safe assets.

To develop a measure of the unobserved convenience yield on U.S. safe assets derived by foreign investors, we focus on U.S. Treasury bonds as the safest among the set of U.S. safe assets. U.S. Treasury bonds are known to offer liquidity and safety services to investors which results in lower equilibrium returns to investors from holding such bonds (see Krishnamurthy and Vissing-Jorgensen, 2012; Greenwood, Hanson and Stein, 2015). Covered interest rate parity cannot hold for Treasurys when their ownership produces convenience yields, while foreign bonds do not, even in the absence of frictions. In our model, the foreign convenience yield is proportional to the Treasury basis, the difference in yields between the dollar yield on short-term U.S. Treasury bonds and short-term foreign government bonds, currency-hedged, into U.S. dollars. We measure this wedge using data on spot exchange rates, forward exchange rates, and pairs of government bond yields in two datasets in a panel of countries that starts in 1988. We also build a US/UK time series that starts in 1970 and ends in 2017.[2]

The U.S. Treasury basis is generally negative and widens during global financial crises, consistent with the picture from Figure 1. Using our new convenience-yield valuation equation for the exchange rate, we implement a Campbell-Shiller-style decomposition of exchange rate innovations into a cash flow component which tracks interest rate differences, a discount rate component which tracks currency risk premia, and, finally, a convenience yield component. In Froot and Ramadorai (2005)'s decomposition, the latter would have been absorbed by the discount rate component. The convenience yield channel is quantitatively important: it accounts for at least 33% of the real exchange rate variance, compared to 13% for the cash flow component.

Innovations in the Treasury basis account for between 13% to 41% of the variation in the spot dollar exchange rate with the right sign: a decrease in the 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

[2]In earlier work, Du, Im and Schreger (2018) also study the Treasury basis, but for a different purpose. We use this metric to study the relation between the convenience yield on U.S. Treasury bonds and variation in the dollar exchange rate. We show theoretically why the convenience yield should affect exchange rate determination, and show empirically that it has strong explanatory power for explaining exchange rate movements. Additionally, Du, Im and Schreger (2018) delve into the term structure of the convenience yield, while we focus on the short-maturity convenience yield which is more responsive to safe asset demand by foreigners. An abridged version of the theory in this paper as well as results similar to that presented in Table 3 are published in Jiang, Krishnamurthy and Lustig (2018).

and Rose, 1995). Using a Vector Autoregression to model the joint dynamics of the Treasury 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 dollar over the next quarter. Subsequently, 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.

Finally, our lens into understanding safe-asset demand is through the measured convenience yield on U.S. Treasurys, but our theory encompasses a foreign convenience demand for all dollar-denominated safe assets. We present evidence consistent with this point by examining the LIBOR basis and the basis constructed using the bonds of KfW, a supranational backed by the German government.

Researchers have struggled to identify the fundamental drivers of the exchange rate (the 'exchange rate disconnect puzzle', see Froot and Rogoff (1995); Frankel and Rose (1995)). We help resolve this puzzle by linking variation in safe asset demand to quarterly contemporaneous variation in exchange rates, and finding regression R^2s as high as 41%. We also show that our safe asset demand measure predicts exchange rate changes over horizons up to 3 years with R^2s on these forecasting regressions as high as 19%. We also show that our measure has statistical power out-of-sample in forecasting exchange rate changes, albeit weaker than in-sample.[3]

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. Real exchange rates do not co-vary with macroeconomic quantities in the right way (see Backus and Smith, 1993; Kollmann, 1995). The existence of convenience yields introduces a wedge between the real exchange rates and the difference in the log pricing kernels that may help to resolve this issue.

A large class of theoretical models predict that interest rates should drive exchange rates. Some papers have confirmed this finding, but the results are mixed and do not always conform to theory. For example, Eichenbaum and Evans (1995) find that an unexpected increase in home rates appreciates the home currency, as would be suggested by textbook models. Textbook models also predict that the exchange rate should depreciate after an

[3] In high frequency data, there is evidence for order flows driving exchange rate dynamics. (see Jeanne and Rose, 2002; Evans and Lyons, 2002; Hau and Rey, 2005, for recent examples).

unexpected increase in the home interest rate, but U.I.P. is soundly rejected in the data, as is well known since the seminal work of Hansen and Hodrick (1980); Fama (1984): the currency of the high interest rate currency subsequently appreciates on average. Recently, Engel (2016); Valchev (2016); Dahlquist and Penasse (2016) show that an increase in the short-term interest rate forecasts a short-horizon appreciation in the dollar, which is inconsistent with standard models, and a long-horizon depreciation, consistent with theoretical models. Engel (2016) shows that these dynamics cannot be matched by standard asset pricing models. Engel (2016) describes an exchange rate model with a role for liquidity services provided by short-term debt that could explain the dynamics of U.I.P. deviations. We find that the short-horizon appreciation in response to an interest rate shock disappears when convenience yield shocks are introduced.

Our results lend empirical support to theories of the U.S. as the provider of world safe assets. There is ample empirical evidence that non-US borrowers tilt the denomination of their borrowings (loans, deposits, bonds) especially towards the US dollar: see Shin (2012) and Ivashina, Scharfstein and Stein (2015) on bank borrowing and Bruno and Shin (2017) on corporate bond borrowing. Moreover, foreign investors tilt their portfolio towards owning US dollar-denominated corporate bonds when they invest in bonds denominated in foreign currencies (see Maggiori, Neiman and Schreger, 2017). The evidence on the dollar bias in credit markets is silent on whether demand or supply factors are the main drivers.[4] Our evidence from sovereign bond markets supports a demand-based explanation. The Treasury dollar basis is typically negative and reductions in the basis appreciate the dollar, suggesting that foreign investors' special demand for dollar-denominated assets lowers their expected returns.

The evidence we present 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. Moreover, we 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.

The paper proceeds as follows. Section 1 sets out the stylized facts regarding the U.S. Treasury basis.

[4]The quantity evidence does not identify whether the bias towards dollar assets is demand or supply-driven.

Section 2 lays out the convenience yield theory of exchange rates. Section 3 and 4 take the theory to data. The appendix provides further derivations of the theory, additional empirical evidence, and details our data sources.

1 The U.S. Treasury Basis: Stylized Facts

We define the U.S. Treasury basis as the difference between the yield on a cash position in U.S. Treasurys $y_t^{\$}$ and the synthetic dollar yield constructed from a cash position in a foreign bond, which earns a yield y_t^* in foreign currency, that is hedged back into dollars:

$$x_t^{Treas} \equiv y_t^{\$} + (f_t^1 - s_t) - y_t^*. \tag{1}$$

Here s_t is the log of the foreign-per-dollar nominal exchange rate and f_t^1 is the log of the forward exchange rate. x_t^{Treas} measures the violation of covered interest rate parity (C.I.P.) constructed from U.S. Treasury and foreign government bond yields. A negative U.S. Treasury basis means that the U.S. Treasurys are overvalued relative to its foreign counterpart.

We also construct the LIBOR basis (x_t^{LIBOR}) using LIBOR rates. There is a recent literature examining the failure of the LIBOR C.I.P. condition (see Du, Tepper and Verdelhan (2017)). Our Treasury basis measure is closely related to the LIBOR C.I.P. deviation. That deviation is constructed using LIBOR rates for home and foreign countries while our basis measure is the same deviation but constructed using government bond yields for home and foreign countries.

We use two datasets, a panel of countries that spans 1988-2017 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. In order to ensure results from Treasury basis and results from Libor basis are comparable, we only include the country/quarter observations if both Treasury basis and Libor basis are available.[5] The data comprises the bilateral exchange

[5] Because New Zealand's 12-month Treasury yield is available from 1987 whereas its 12-month Libor rate is available from 1996, and Sweden's 12-month Treasury yield is available from 1984 whereas its 12-month Libor rate is available from 1991, we leave out some observations in which Treasury basis is available but Libor basis is not. We have confirmed our main empirical results are robust in the sample that contains these additional observations of Treasury basis

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. We convert the daily data to quarterly frequencies using end-of-quarter observations on the same day for bond yields, interest rates, forward rates and exchange rates. There are some quarters for which all of the data are not available on the last day of the quarter, in which case we find a date earlier in the quarter, but as close to the end-of-quarter as possible, when all data are available. The Data Appendix contains information about data sources.

We construct the Treasury and LIBOR basis using the 12-month yields and forwards for each currency following (1). In each quarter, we construct the mean basis across all the countries in the panel for that quarter. Figure 2 plots these series.

[Figure 2 about here.]

The dotted line is the mean LIBOR basis of the U.S. dollar against the basket of currencies. The pre-crisis spikes in the average LIBOR basis are driven by idiosyncracies of LIBOR rates in Sweden in 1992 and Japan in 1995 (note the difference between the mean and median LIBOR basis in 1992 and 1995). The LIBOR 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 solid line is the mean Treasury basis. Unlike the LIBOR basis, the Treasury basis has always been negative and volatile. Table 1 reports the time-series moments of the Treasury basis, the Libor basis, the 12M Treasury yield difference and the 12M forward discount. The average mean Treasury basis is -25 bps per annum, which means that foreign investors are willing to give up 25 bps per annum more for holding currency-hedged U.S. Treasurys than their own bonds. The standard deviation of the mean Treasury basis is 24 bps per quarter. In contrast, the average LIBOR basis is -7 bps.

When LIBOR C.I.P. holds, the Treasury basis is simply the difference between the U.S. Treasury-LIBOR spread and its foreign counterpart:

$$x_t^{Treas} = \left(y_t^{\$} - y_t^{\$,Libor}\right) - \left(y_t^{*} - y_t^{*,Libor}\right). \qquad (2)$$

Before the financial crisis, when the LIBOR basis was close to zero (-4 bps), the Treasury basis (-27 bps) is mostly due to this differential in the Treasury-LIBOR spreads. The U.S. LIBOR-Treasury spread is 23 bps larger than its foreign counterpart. During and after the crisis, this U.S. LIBOR-Treasury spread is only 7 bps per annum higher than the foreign one, while the average LIBOR basis increases to -13 bps per annum. Over the entire sample, the Treasury and LIBOR basis have a correlation of 0.36. This correlation is largely driven by the post-crisis relation where the correlation 0.56. Finally, the Treasury basis is negatively correlated (-0.27) with the U.S.-foreign Treasury yield difference and the forward discount.

[Table 1 about here.]

[Table 2 about here.]

Table 2 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 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. 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. Note that OIS data is only available since 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).

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. The average US/UK Treasury basis is 0.84 bps per annum. On average, U.K. investors are close to indifferent between holding U.S. Treasurys on a currency-hedged basis and holding gilts. However, the standard deviation is 48 bps. per quarter. 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, which is sometimes larger than that of US bonds particularly in the 1970s.[6]

[Figure 3 about here.]

2 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 bonds denominated in dollars (foreign currency). We derive bond and exchange rate pricing conditions that must be satisfied in asset market equilibrium.

We develop our basic results in a simplifed case for expositional purposes. First, we focus on the pricing of U.S. Treasury bonds as the asset that produces convenience yields. As we will make clear, our theory is broadly about the pricing of U.S. dollar safe assets and not only U.S. Treasury bonds. On the other hand,

[6] Additionally, the basis is volatile in the 1970s and frequently positive. Suffering a balance-of-payments deficit in the early 1970s, the Nixon administration decided to suspend convertibility of the dollar into gold in 1973 and effectively ended the Bretton-Woods system. This action led to considerable uncertainty in the international monetary system, with some observers noting that foreigners became unwilling to continue to hold the dollar assets necessary to finance the balance-of-payments deficit (see Bach et al. (1972) and Farhi and Maggiori (2017)). Additionally, the U.K. suffered a balance-of-payments crisis in 1976, turning to the IMF for a large loan. These reductions in asset demand, first for U.S. and then for U.K. bonds, are apparent in the figure: the basis turns positive in 1973 before subsequently turning negative in 1976.

our empirical work is specifically about the measured convenience yields on U.S. Treasury bonds, so that the theoretical expressions we derive for U.S. Treasury bonds are the relevant ones to interpret the empirical work. Second, for now, we assume that only U.S. bonds produce convenience yields.

2.1 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 Treasury 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 investor's Euler equation is given by:

$$\mathbb{E}_t\left(M_{t+1}^* e^{y_t^*}\right) = 1 \tag{3}$$

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,

$$\mathbb{E}_t\left(M_{t+1}^* \frac{S_{t+1}}{S_t} e^{y_t^\$}\right) = e^{-\lambda_t^*}, \qquad \lambda_t^* \geq 0. \tag{4}$$

The expression on the left side of the equation is standard. On the right side, we allow foreign investors in U.S. Treasurys to derive a convenience yield, λ_t^*, on their Treasury bond holdings. This λ_t^* is asset-specific. We broaden the analysis to other safe U.S. assets in Sections 2.4 and 2.5.

If the convenience yield rises, lowering the right side of equation (4), the required return on the investment in U.S. Treasury bonds (the left side of the equation) falls; either the expected rate of dollar appreciation declines or the yield $y_t^\$$ 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, (3) can be rewritten as,

$$\mathbb{E}_t\left(m_{t+1}^*\right) + \frac{1}{2} Var_t\left(m_{t+1}^*\right) + y_t^* = 0, \tag{5}$$

and (4) as,

$$\mathbb{E}_t\left(m_{t+1}^*\right) + \frac{1}{2} Var_t\left(m_{t+1}^*\right) + \mathbb{E}_t[\Delta s_{t+1}] + \frac{1}{2} var_t[\Delta s_{t+1}] + y_t^\$ + \lambda_t^* - RP_t^* = 0. \tag{6}$$

Here $RP_t^* = -cov_t\left(m_{t+1}^*, \Delta s_{t+1}\right)$ 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:

Lemma 1. *The expected return in levels on a long position in dollars earned by a foreign investor is decreasing in the convenience yield:*

$$\mathbb{E}_t[\Delta s_{t+1}] + \left(y_t^{\$} - y_t^*\right) + \frac{1}{2} var_t[\Delta s_{t+1}] = RP_t^* - \lambda_t^* \tag{7}$$

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, given that US yields are typically lower than foreign yields. On the right hand side, the first term is the familiar currency risk premium demanded by a foreign investor going long US Treasurys in dollars. The second term is the convenience yield attached by foreign investors to U.S. Treasurys: 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, $RP_t^* = 0$, U.I.P. fails when the convenience yield is greater than zero, as previously pointed out by Valchev (2016).

2.2 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 deprecation 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:

$$\mathbb{E}_t\left(M_{t+1}^{\$} \frac{S_t}{S_{t+1}} e^{y_t^*}\right) = 1. \tag{8}$$

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

$$\mathbb{E}_t\left(M_{t+1}^{\$} e^{y_t^{\$}}\right) = e^{-\lambda_t^{\$}}. \quad \lambda_t^{\$} \geq 0. \tag{9}$$

$\lambda_t^{\$}$ is asset-specific. An increase in the U.S. investor's convenience yield lowers U.S. Treasury bond yields, holding the SDF fixed: $y_t^{\$} = \rho_t^{\$} - \lambda_t^{\$}$, where $\rho_t^{\$} = -\log \mathbb{E}_t\left(M_{t+1}^{\$}\right)$. We assume log-normality and rewrite these equations to derive an expression for the carry trade return,

$$\left(y_t^* - y_t^\$\right) - \mathbb{E}_t[\Delta s_{t+1}] + \frac{1}{2} var_t[\Delta s_{t+1}] = RP_t^\$ + \lambda_t^\$. \tag{10}$$

where, $RP_t^\$ = -cov_t\left(m_{t+1}^\$, -\Delta s_{t+1}\right)$ 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 (7) and (10) to derive a cross-country restriction on the convenience yields imputed to Treasurys and the currency risk premia,

$$\lambda_t^* - \lambda_t^\$ = RP_t^\$ + RP_t^* - var_t[\Delta s_{t+1}]. \tag{11}$$

All else equal, an increase in λ_t^* has to be accompanied by a proportional increase in the risk premium U.S. investors ($RP_t^\$$) demand on foreign bonds, if we enforce the U.S. investor's Euler equation for foreign bonds. In an incomplete markets setting, the increase in the risk premium is a natural equilibrium outcome given that U.S. investors would increase their exposure to foreign exchange risk via the foreign bond carry trade in response to the expected depreciation of the dollar.

Thus far, we have only considered the Euler equations for risk-free assets. This raises the question of what happens when we enrich the menu of traded assets. We discuss this in section A.1 of the appendix.

2.3 Exchange rates and convenience yields

By forward iteration on eqn. (7), 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).[7]

Lemma 2. *The level of the nominal exchange can be written as:*

$$s_t = \mathbb{E}_t \sum_{\tau=0}^{\infty} \lambda_{t+\tau}^* + \mathbb{E}_t \sum_{\tau=0}^{\infty} (y_{t+\tau}^\$ - y_{t+\tau}^*) - \mathbb{E}_t \sum_{\tau=0}^{\infty} \left(RP_{t+\tau}^* - \frac{1}{2} Var_{t+\tau}[\Delta s_{t+\tau+1}] \right) + \bar{s}. \tag{12}$$

The term $\bar{s} = \mathbb{E}_t[\lim_{\tau \to \infty} s_{t+\tau}]$ *is constant under the assumption that the nominal exchange rate is stationary.*[8]

[7] Campbell and Clarida (1987); Clarida and Gali (1994) developed an early version of this decomposition that imposed U.I.P.

[8] There is empirical support for the proposition that the real dollar exchange rate is stationary. Over the last 30 years, which is

The exchange rate level is determined by yield differences, the convenience yields, and the currency risk premia. 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.

Alternatively, we can rewrite this equation as the sum of the convenience yield differentials, the fundamental yield differences, stripped of the convenience yields, and the risk premia:

$$s_t = \mathbb{E}_t \sum_{\tau=0}^{\infty} (\lambda^*_{t+\tau} - \lambda^\$_{t+\tau}) + \mathbb{E}_t \sum_{\tau=0}^{\infty} (\rho^\$_{t+\tau} - \rho^*_{t+\tau}) - \mathbb{E}_t \sum_{\tau=0}^{\infty} \left(RP^*_{t+\tau} - \frac{1}{2} Var_{t+\tau}[\Delta s_{t+\tau+1}] \right) + \bar{s}. \quad (13)$$

where $\rho^\$_t = -\log \mathbb{E}_t \left(M^\$_{t+1} \right)$ is the fundamental (no convenience effect) bond yield in dollars, and likewise for foreign. Expression (13) clarifies that the exchange rate responds only to the difference in perceived convenience yields.

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,

$$q_t = s_t + p^\$_t - p^*_t. \quad (14)$$

We substitute the real exchange rate expression, (14), into the earlier expressions for nominal exchange rates and rewrite to find:

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

$$q_t = \mathbb{E}_t \sum_{\tau=0}^{\infty} \lambda^*_{t+\tau} + \mathbb{E}_t \sum_{\tau=0}^{\infty} (r^\$_{t+\tau} - r^*_{t+\tau}) - \mathbb{E}_t \sum_{\tau=0}^{\infty} \left(RP^*_{t+\tau} - \frac{1}{2} Var_{t+\tau}[\Delta s_{t+\tau+1}] \right) + \bar{q}. \quad (15)$$

our data sample, inflation has been highly correlated and similar across developed countries, so that the nominal exchange rate is also plausibly stationary.

where, $\bar{q} = \mathbb{E}_t[\lim_{\tau\to\infty} q_{t+\tau}]$ is constant under the assumption that the real exchange rate is stationary. The terms $r_t^\$$ and r_t^* are the real interest rates, i.e., $y_t^\$ - \mathbb{E}_t[\Delta p_{t+1}^\$]$ is the real dollar interest rate.

2.4 Cash Treasurys, Synthetic Treasurys, and the Treasury basis

The key measure in our theory is λ_t^*. We next show this object can be inferred from the Treasury basis. To do so, we consider the foreign investor's Euler equation for an investment in a foreign government bond that is swapped into dollars via the forward market. This investment has the investor owning a package of safe foreign government bond and a forward position. Together, these give the investor a dollar asset, but one that is not as safe and liquid as the cash position in U.S. Treasurys because it involves some bank counterparty risk, and a bond and forward that are not as liquid as U.S. Treasury bonds. Thus, we posit that it provides a smaller convenience yield than U.S. Treasurys:

$$\mathbb{E}_t\left[M_{t+1}^*\frac{S_{t+1}}{F_t^1}e^{y_t^*}\right] = e^{-\beta^{*,h}\lambda_t^*},$$

where F_t^1 denotes the one-period forward exchange rate, in foreign currency per dollar, and $\beta^{*,h}\lambda_t^*$, with $0 < \beta^{*,h} < 1$, denotes the convenience yield on the bond+forward investment. We can use this equation along with the foreign investor's Euler equation for the U.S Treasury bond, (4), to find an expression for the unobserved U.S. Treasury convenience yield.

Lemma 4. *λ_t^*, the foreign convenience yield on U.S. Treasury bonds, is proportional to the Treasury basis:*

$$x_t^{Treas} = -(1-\beta^{*,h})\lambda_t^*. \tag{16}$$

This lemma is the key to our empirical work as it provides an avenue to testing our theory linking λ_t^* and the dollar exchange rate.[9,10] We have motivated this measure by thinking about a foreign bond swapped into

[9] The observation that Treasury-based C.I.P. violations may be driven by convenience yields was pointed out by Adrien Verdelhan in a discussion at the Macro Finance Society (2017).

[10] By comparing a cash dollar Treasury bond to a synthetic dollar foreign government bond and using this spread, the basis, to measure λ_t^*, we are positing that dollar safe asset investors are doing both of these transactions to own safe dollar bonds. That is, we are reading off their first-order-condition to learn about λ_t^*. Consider another way of reading the basis. A Canadian investor who swapped a U.S. Treasury into Canadian dollars would receive a lower return, by exactly the basis, on their investment compared to the cash position in the Canadian government bond. In this case, we might say that by swapping the Treasury to Canadian dollars, the investor is investing in a more liquid Canadian dollar bond. But this seems implausible: the package of an illiquid swap and the Treasury bond is likely less liquid than the Canadian government bond. Investors looking to own safe Canadian dollar bonds

dollars, but as we show next, we can also understand the measure in terms of LIBOR and banks.

2.5 Convenience yields on LIBOR deposits, the LIBOR basis, and the Treasury basis

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. This section introduces dollar LIBOR deposits which also offer convenience yields to foreign investors, but less so than U.S. Treasurys. That is, as noted earlier, our theory posits that investors receive convenience utility from U.S. safe assets, a set that includes both U.S. Treasurys and bank deposits. We first show how to understand the LIBOR basis and safe asset demand in this case, and then offer another way to understand the Treasury basis.

Foreign and domestic investors have access to U.S. LIBOR markets, and they satisfy the following Euler equations:

$$\mathbb{E}_t\left(M_{t+1}^{\$}e^{y_t^{\$,Libor}}\right)=e^{-\beta_t^{\$}\lambda_t^{\$}}$$
$$\mathbb{E}_t\left(M_{t+1}^{*}\frac{S_{t+1}}{S_t}e^{y_t^{\$,Libor}}\right)=e^{-\beta^{*}\lambda_t^{*}}$$

where $\beta^{\$}\lambda_t^{\$}$ ($\beta^{*}\lambda_t^{*}$) denotes the convenience yield from a cash position in dollars derived by U.S. (foreign) investors, and these βs are less than one.

Banks issue foreign and dollar deposits that pay LIBOR at rates $y_t^{\$,Libor}$ and $y_t^{*,Libor}$. The dollar deposits offer a convenience yield to investors but not to the banks, so that banks will wish to issue these deposits in equilibrium. Consider a given bank that has a mix of deposits in both currencies in (dollar-equivalent) amounts $(\bar{\theta}_t^{B,\$},\bar{\theta}_t^{B,*})$. We suppose the mix is optimal for the bank given asset/liability management concerns and the currency mix of the rest of its balance sheet.[11] Next, suppose that the bank also trades in the forward market. Clearly if the convenience yield on dollar deposits rises relative to foreign deposits, the bank will want to supply more of these dollar deposits and hedge these using the forward market to maintain its optimal currency mix.

are not likely to be doing this swap, so that we learn nothing about these investors from the basis.

[11] If bank deposits offer convenience yields, than banks will create these deposits, and the limit on such deposit creation will be governed by bank costs in creating the deposits. See the model of Krishnamurthy and Vissing-Jorgensen (2015) for one specification of intermediaries doing asset/liability management and creating money where the cost is in terms of collateral backing. We have suppressed the specification of these costs to not stray from our primary analysis which is exchange rate determination. Think of the optimal mix $(\bar{\theta}_t^{B,\$},\bar{\theta}_t^{B,*})$ as being driven by these costs.

Then the bank chooses θ_t^B, the quantity of this swap, to achieve deposit mix $(\bar{\theta}_t^{B,\$} + \theta_t^B, \bar{\theta}_t^{B,*} - \theta_t^B)$. If there is greater demand for dollar deposits the bank will on the margin increase θ_t^B. Suppose the bank solves:

$$\max_{\theta_t^B} \theta_t^B \left(y_t^{*,Libor} - (f_t - s_t) - y_t^{\$,Libor} \right) - \frac{\kappa}{2} \left(\theta_t^B \right)^2 .$$

Here κ is a capital/leverage cost associated with doing the forward and hedging the dollar deposits. The term $y_t^{*,Libor} - (f_t - s_t) - y_t^{\$,Libor}$ is the funding cost reduction that the bank gets when taking advantage of the dollar convenience yield. The F.O.C. for the bank is,

$$\begin{aligned} -\kappa \theta_t^B &= y_t^{\$,Libor} - y_t^{*,Libor} + (f_t - s_t) \\ &= x_t^{LIBOR} \end{aligned}$$

where x_t^{LIBOR} denotes the LIBOR basis. If $y_t^{\$,Libor}$ is particularly low, e.g., driven by an increase in demand for dollar deposits, then x_t^{LIBOR} will rise and banks will increase the supply of dollar deposits, θ_t^B, while swapping these dollars deposits back into foreign currency to keep their exchange rate exposure unaffected. Suppose there are many banks and denote the aggregate quantity of dollar deposits supplied in equilibrium as Θ_t^B. Then, the equilibrium LIBOR basis is given by:

$$x_t^{LIBOR} = -\kappa \Theta_t^B. \tag{17}$$

Lemma 5. *The LIBOR basis depends on foreign demand for dollar deposits as follows:*

- *When banks face no capital/leverage costs in doing swaps and $\kappa = 0$, the LIBOR basis is zero and independent of Θ_t^B.*
- *When $\kappa > 0$, the LIBOR basis becomes more negative as the demand for dollar safe assets rises.*

In the frictionless case, as κ goes to zero, banks actively trade in the forward to earn the convenience yield on dollar deposits while not altering their exchange rate exposure. In equilibrium, the price of the forward will adjust to equalize these margins and the LIBOR C.I.P. deviation goes to zero. Perhaps surprisingly. the forward price, f_t^1, can embed a convenience yield. We come to this later when interpreting carry trade relations.

In an influential recent paper, Du, Tepper and Verdelhan (2017) document that the LIBOR basis was near zero pre-crisis and has often been significantly different than zero post-crisis. They show that the movements in the LIBOR basis are closely connected to frictions in financial intermediation that prevent arbitrage activities.[12] Our lemma shows, consistent with the findings of Du, Tepper and Verdelhan (2017), that when $\kappa > 0$, LIBOR C.I.P. will fail. More novel, our theory implies that when $\kappa > 0$, x_t^{LIBOR} will, like λ_t^*, reflect foreign investors's demand for safe dollar assets. We will verify this prediction in the data post-crisis.

We next reconsider the Treasury basis in light of the LIBOR basis:

$$x_t^{Treas} = y_t^{\$} - y_t^* + f_t - s_t = (y_t^{\$} - y_t^{\$,Libor}) - (y_t^* - y_t^{*,Libor}) + x_t^{LIBOR}. \tag{18}$$

The Treasury basis is the sum of the LIBOR basis and the difference between the two currency's Treasury-LIBOR spreads. We can further rewrite this expression as,

$$x_t^{Treas} = -(1-\beta^*)\lambda_t^* - \kappa\Theta_t^B$$

where we have used the relation that the Treasury-LIBOR spread is zero in the foreign country and equal to $(1-\beta^*)\lambda_t^*$ in dollars. We note that the Treasury basis measures the foreign demand for U.S. safe assets through both the Treasury convenience yield λ_t^* and through movements in the quantity of dollar deposits (Θ_t^B).

Returning to case where $\kappa = 0$, which appears to the relevant case for most of our sample when LIBOR C.I.P. holds, we note another way of understanding why the Treasury basis measures the foreign convenience yield:

Lemma 6. *When $\kappa = 0$, the Treasury basis provides a measure of λ_t^*, the foreign convenience yield on U.S. Treasury bonds:*

$$\lambda_t^* = -\frac{x_t^{Treas}}{1-\beta^*}. \tag{19}$$

The key behind this lemma is that both Treasury bond yields and LIBOR rates reflect the foreign convenience yield, but differentially. Thus the difference, as reflected in the basis, directly measures the foreign convenience yield. In this version of the model, where only U.S. bonds have convenience yields, the term $\left(y_t^{\$} - y_t^{\$,Libor}\right)$ is what captures the foreign convenience yield.[13] When both foreign and U.S. bonds carry convenience yields, the

[12] Other papers have come to similar conclusions regarding the importance of financial frictions and capital controls (see Ivashina, Scharfstein and Stein, 2015; Gabaix and Maggiori, 2015; Amador et al., 2017; Itskhoki and Mukhin, 2017).

[13] When LIBOR C.I.P. holds, the convenience yield from a currency-hedged position in Treasurys equals the U.S. LIBOR-Treasury spread. From the standpoint of the U.S. investor, $x_t^{Treas} = -(1-\beta^{\$})\lambda_t^{\$}$. The Treasury basis is also related to U.S. investor's

difference in the LIBOR-Treasury spreads across both countries is the right measure of the convenience yield as we show in the appendix.

2.6 Summary

We arrive at four key implications of our theory relating the Treasury basis to the dollar exchange rate.

Proposition 1. Treasury basis and the dollar

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

$$s_t = -\mathbb{E}_t \sum_{\tau=0}^{\infty} \frac{x_{t+\tau}}{1-\beta^*} + \mathbb{E}_t \sum_{\tau=0}^{\infty} (y^{\$}_{t+\tau} - y^{*}_{t+\tau}) - \mathbb{E}_t \sum_{\tau=0}^{\infty} \left(RP^*_{t+\tau} - \frac{1}{2} Var_{t+\tau}[\Delta s_{t+\tau+1}] \right) + \bar{s}. \tag{20}$$

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

$$q_t = -\mathbb{E}_t \sum_{\tau=0}^{\infty} \frac{x_{t+\tau}}{1-\beta^*} + \mathbb{E}_t \sum_{\tau=0}^{\infty} (r^{\$}_{t+\tau} - r^{*}_{t+\tau}) - \mathbb{E}_t \sum_{\tau=0}^{\infty} \left(RP^*_{t+\tau} - \frac{1}{2} Var_{t+\tau}[\Delta s_{t+\tau+1}] \right) + \bar{q}. \tag{21}$$

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

3. *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:*

$$\mathbb{E}_t[\Delta s_{t+1}] + \left(y^{\$}_t - y^*_t \right) = RP^*_t - \frac{1}{2} var_t[\Delta s_{t+1}] + \frac{x^{Treas}_t}{1-\beta^*} \tag{22}$$

4. *The expected log return to a foreign investor of going long the dollar via the forward contract is:*

$$\mathbb{E}_t[\Delta s_{t+1}] - (f^1_t - s_t) \quad = \quad RP^*_t - \frac{1}{2} var_t[\Delta s_{t+1}] + \frac{\beta^*}{1-\beta^*} x^{Treas}_t. \tag{23}$$

Our theory also has implications for the LIBOR basis that we take to the data:

convenience valuation of Treasury bonds and LIBOR deposits. As noted earlier, for us to find a relation between convenience yields and exchange rates, we must have that $\lambda^{\$}_t \neq \lambda^*_t$, which further implies that $\beta^{\$} \neq \beta^*$.

Proposition 2. LIBOR basis and the dollar

Consider the case where $\kappa > 0$. Suppose that when the foreign investor's convenience demand for US safe assets rises, their demand for dollar LIBOR assets also rises, so that Θ_t^B rises when λ_t^* rises. Then,

1. *x_t^{LIBOR} will be positively correlated with x_t^{Treas}.*
2. *x_t^{LIBOR} will explain movements in the dollar exchange rate.*

2.7 Convenience yields on foreign bonds

Thus far we have assumed that foreign government bonds generate no convenience utility for its holders. This allowed us to most transparently explain how the convenience yield affects exchange rate determination. In the appendix, we consider the realistic case when foreign bonds also carry a convenience yield. The notation is more cumbersome, but the economics follows naturally. We show that all of the prior results continue to hold with the twist that λ_t^* should be interpreted as the convenience yield foreigners derive from holding U.S. Treasurys in excess of the convenience yields they derive from holding their own bonds, and $\lambda^{\$}$ should be interpreted as the convenience yield U.S. investors derive from U.S. Treasurys in excess of the yield derived from the foreign bonds. Additionally, x_t^{Treas} should be interpreted as the convenience yield foreigners derive from holding U.S. Treasurys relative to U.S. LIBOR assets, relative to the same object in foreign bonds. Appendix A.2 provides the details of the derivations.

3 Joint Dynamics of Dollar Exchange Rates, Treasury Bases, and Convenience Yields

We next turn to providing empirical support for the propositions outlined in the theory. We begin by showing that in univariate regressions, innovations to the Treasury basis correlate with innovations in the dollar exchange rate in both the cross-country panel and the US/UK data. This provides support for result 1 in Proposition 1. We also show that the LIBOR basis comoves with the exchange rate in the post-crisis sample but not the pre-crisis sample, consistent with Proposition 2. We combine these results in a vector auto-regression (VAR) allowing us to fully describe the dynamic relation between the exchange rate and the basis. Finally, we provide a variance decomposition for exchange rates that quantifies how much basis shocks explain exchange rate movements.

3.1 Maturity

Before turning to the results, we discuss the choice of bond and forward maturity in measuring the Treasury basis, which is an important issue for the empirical strategy. As we have shown, the value of the exchange rate reflects the entire future stream of convenience yields, suggesting that we use longer maturities when measuring convenience yields. However, long-maturity Treasury bonds carry considerable interest rate risk and may not satisfy the safe asset demand of foreign investors. In this case, their prices will not reflect a convenience yield. In fact, Du, Im and Schreger (2018) document that convenience yields when measured from long-maturity Treasury bonds have been negative recently, indicating that the safe-asset demand effects are not contained in these prices. Throughout this paper we report results using the 12-month maturity.[14]

3.2 Variation in the Treasury Basis and the Dollar

We denote the cross-sectional mean basis in the panel as $\overline{x}_t^{Treas}$. Similarly, we use $\overline{y}_t^{*} - y_t^{\$}$ to denote the cross-sectional average of yield differences, and $\overline{s}_t$ 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. We construct quarterly AR(1) innovations in the basis by regressing $\overline{x}_t^{Treas} - \overline{x}_{t-1}^{Treas}$ on $\overline{x}_{t-1}^{Treas}$ and $y_{t-1}^{\$} - \overline{y}_{t-1}^{*}$ and computing the residual, $\Delta\overline{x}_t^{Treas}$.[15] We then regress the contemporaneous quarterly change in the spot exchange rate, $\Delta\overline{s}_t \equiv \overline{s}_t - \overline{s}_{t-1}$, on this innovation. Note that we have verified the robustness of the results reported here to the case where the innovation $\Delta\overline{x}_t^{Treas}$ is the simple change in $\overline{x}_t^{Treas}$ rather than the AR(1) innovation. The results are reported in the Separate Online Appendix.

Table 3 reports the results. From columns (1), (3), (5), (6) and (8), we see that the innovation in the Treasury basis strongly correlates with changes in the exchange rate. The R^2s are quite high for exchanges

[14] We have also examined the 3-month maturity. See Section D.6 of the Separate Appendix. The results using the 3-month are broadly consistent with the 12-month results but uniformly weaker, likely because the 3-month basis is a noisy measure of the long-term expectation term that drives exchange rates under our theory.

[15] Because our data is an unbalanced panel, we construct country-level changes in the basis first, and then take the cross-country average to arrive at the change in the basis.

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 16.1% to 42.4% of the variation in the dollar's rate of appreciation. The sign is negative as predicted by Proposition 1. 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) below its mean coincides with a 0.96% 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 (20) 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 (20), to rationalize the 0.96% appreciation we need a value of $1 - \beta^*$ of $\frac{5.3}{96} = 0.055$.

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. As we discussed in section 2.5, frictions in the banking sector's intermediation in LIBOR markets lead the LIBOR basis to also reflect foreign convenience demand. Thus both the exchange rate and the LIBOR basis reflect convenience demand, driving the post-crisis relation between these variables. In the pre-crisis sample there is no relation between the LIBOR basis and the appreciation of the dollar because banks act to drive the LIBOR basis to zero.

[Table 3 about here.]

Column (3) of Table 3 includes the contemporaneous and the lagged innovation to the basis. This specification increases the R^2 to 23.5%. The explanatory 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.[16]

Column (4) of the table includes the innovation in the interest rate differential, $y^{\$} - y^*$, constructed analogous to the basis innovation. We see that increases in this interest rate spread has significant explanatory power in

[16] The existence of momentum also indicates that $\frac{1}{1-\beta^*}$ 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 3.4.

our sample. A rise in the US rate relative to foreign appreciates the currency, which is what textbook models of exchange rate determination will predict (and is what equation (12) predicts). We include this covariate in column (5) along with the basis innovation. The R^2 rises to 42.4% and the coefficient estimates and standard errors are nearly unchanged. This is because the basis innovation and interest rate innovation are nearly uncorrelated in this sample (note: the levels are negatively correlated).[17]

[Figure 4 about here.]

[Table 4 about here.]

Next we turn to the US/UK data. The sample is longer, going back to 1970Q1. Figure 4 plots the real exchange rate in units of GBP-per-USD (dashed line) against the US/UK Treasury basis (full line). 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 4 presents regressions analogous to that of Table 3. We again see a strong relation between shocks to the basis and real exchange rate changes. The relation becomes stronger later in the sample.[18] In the sample from 1990 onwards, the regression R^2 is 28.4% which is a remarkably strong fit. The coefficient in column (4) of the Table indicates that a 10 basis point increase in the basis is correlated with an 0.34% depreciation in the US dollar against the pound. The coefficients using the full sample are smaller than that of Table 3. For column (5), where the sample starts in 1990, the coefficient of -11.67 is similar in magnitude to our earlier estimates.

Column (2) considers the innovation in the interest rate differential as a regressor. In this sample in contrast to the cross-country sample, the interest rate differential has almost no explanatory power for the exchange rate. As noted in the introduction, the prior evidence linking interest rate changes and exchange rates is mixed and this is a clear example of this pattern. The source of the difference is the time period: If we focused on the sample from 1990 onwards, the interest rate differential has explanatory power similar to the result in Table 3.

[17]In the Online Appendix, we split our sample to the dates in which the Treasury basis is above or equal to the 25th percentile of its distribution, and the dates in which it is below. We find that the association between the Treasury basis and the US dollar's exchange rate continues to hold in the subsample in which the Treasury basis does not take extremely negative values. As discussed in the previous section, in this subsample investors impute a lower convenience yield on the US Treasury.

[18]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 4.

Column (3) includes basis innovations and interest rate differential innovations. The coefficients on the basis in column (3) are almost identical to those of column (1).

3.3 Decomposing Dollar Innovations

Using our new convenience-yield valuation equation for the exchange rate in in Proposition 1 , we implement a Campbell-Shiller-style decomposition of real exchange rate innovations into a cash flow component which tracks interest rate differences (the cash flow component), a discount rate component which tracks currency risk premia, and, finally, a convenience yield component. In this decomposition, the different news components are not orthogonal to each other. This procedure does not allow for an identification of the underlying structural shocks. Our analysis extends the seminal work of Campbell and Clarida (1987); Clarida and Gali (1994); Froot and Ramadorai (2005).

We use $i_{t-1} = y^{\$}_{t-1} - y^{*}_{t-1} - \pi^{\$}_t + \pi^{*}_t$ to denote the ex post real yield difference. Define $\boldsymbol{z}'_t = \begin{bmatrix} x_t & i_t & q_t \end{bmatrix}$. We estimate following the first-order VAR for $\boldsymbol{z}_t$:

$$\boldsymbol{z}_t = \boldsymbol{\Gamma}_0 + \boldsymbol{\Gamma}_1 \boldsymbol{z}_{t-1} + \boldsymbol{a}_t,$$

where $\boldsymbol{\Gamma}_0$ is a 3-dimensional vector, $\boldsymbol{\Gamma}_1$ is a 3×3 matrix and $\boldsymbol{a}_t$ is a sequence of white noise random vector with mean zero and variance covariance matrix Σ. The variance covariance matrix is required to be positive definite. The log of the currency excess return is given by $rx_t = q_t - q_{t-1} + i_{t-1}$. The realized risk premium component of the log currency excess return is the realized log excess return minus the convenience yield: $rp_t = rx_t - \frac{1}{1-\beta^*} \times x_{t-1}$. 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. Accordingly, we can define the state as the vector of demeaned variables: $\boldsymbol{y}'_t = \begin{bmatrix} \tilde{rp}_t & \tilde{x}_t & \tilde{i}_t & \tilde{s}_t \end{bmatrix}$. $\boldsymbol{y}_t$ follows a VAR(1) where

$$\boldsymbol{y}_t = \boldsymbol{\Psi}_1 \boldsymbol{y}_{t-1} + \boldsymbol{u}_t,$$

where $\boldsymbol{\Psi}_1$ is the 4×4 matrix defined in (39) in section B of the Separate Appendix and $\boldsymbol{u}_t$ is the 4×1 vector of residuals defined above.

From equation (21), 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 premia (discount rate news). We decompose real exchange rate movements into those components and estimate how much each of the components account for variation in the exchange rate.

$$q_t = -\frac{1}{1-\beta^*}\mathbb{E}_t\sum_{\tau=0}^{\infty} x_{t+\tau} + \mathbb{E}_t\sum_{\tau=0}^{\infty}(r^{\$}_{t+\tau} - r^*_{t+\tau}) - \mathbb{E}_t\sum_{\tau=0}^{\infty}\left(RP^*_{t+\tau} - \frac{1}{2}Var_{t+\tau}[\Delta s_{t+\tau+1}]\right) + \bar{q}. \tag{24}$$

We assume homoskedasticity of exchange rate changes. Note that the risk premium is $RP_t = \mathbb{E}_t rp_{t+1} + \frac{1}{2}Var[\Delta s_{t+1}]$. As a result, the discount rate component of the log exchange rate can be stated as: $\mathbb{E}_t\sum_{\tau=0}^{\infty} RP^*_{t+\tau} = \mathbb{E}_t\sum_{\tau=1}^{\infty} rp_{t+\tau} + constant = \mathbb{E}_t\sum_{\tau=1}^{\infty}(rx_{t+\tau} - \frac{1}{1-\beta^*}x_{t+\tau-1}) + constant$. The resulting expression for the log of the exchange rate is given by:

$$q_t = -\frac{1}{1-\beta^*}\mathbb{E}_t\sum_{\tau=0}^{\infty} x_{t+\tau} + \mathbb{E}_t\sum_{\tau=0}^{\infty} i_{t+\tau} - \mathbb{E}_t\sum_{\tau=1}^{\infty} rp_{t+\tau} + \bar{s}, \tag{25}$$

where we define $CY_t = -\frac{1}{1-\beta^*}\mathbb{E}_t\sum_{\tau=0}^{\infty} x_{t+\tau}$ to be the convenience yield component, $CF_t = \mathbb{E}_t\sum_{\tau=0}^{\infty} i_{t+\tau}$ to be the interest rate difference component, and the last part is the discount rate component: $DR_t = \mathbb{E}_t\sum_{\tau=1}^{\infty} rp_{t+\tau}$. Using the VAR expressions, this simplifies to: $q_t = -\frac{1}{1-\beta^*}\mathbb{E}_t\sum_{\tau=0}^{\infty} x_{t+\tau} + \sum_{j=0}^{\infty}\boldsymbol{e}_3\boldsymbol{\Psi}_1^j\boldsymbol{y}_t - \sum_{j=1}^{\infty}\boldsymbol{e}_1\boldsymbol{\Psi}_1^j\boldsymbol{y}_t + \bar{s}$. From the definition of rp_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:

$$(\mathbb{E}_t - \mathbb{E}_{t-1})rp_t = (\mathbb{E}_t - \mathbb{E}_{t-1})\left[\sum_{j=0}^{\infty} i_{t+j}\right] - (\mathbb{E}_t - \mathbb{E}_{t-1})\left[\sum_{j=0}^{\infty}\frac{1}{1-\beta^*}x_{t+j}\right] - (\mathbb{E}_t - \mathbb{E}_{t-1})\left[\sum_{j=1}^{\infty} rp_{t+j}\right]$$

We compute the discount rate news, the cash flow news and the CY news from the VAR as:

$$\begin{aligned}
N_{DR,t} &= (\mathbb{E}_t - \mathbb{E}_{t-1})\left[\sum_{j=1}^{\infty} rp_{t+j}\right] = \boldsymbol{e}_1'\boldsymbol{\Psi}_1(I-\boldsymbol{\Psi}_1)^{-1}\boldsymbol{u}_t,\\
N_{CF,t} &= (\mathbb{E}_t - \mathbb{E}_{t-1})\left[\sum_{j=0}^{\infty} i_{t+j}\right] = \boldsymbol{e}_3'(I-\boldsymbol{\Psi}_1)^{-1}\boldsymbol{u}_t,\\
N_{CY,t} &= -(\mathbb{E}_t - \mathbb{E}_{t-1})\left[\sum_{j=0}^{\infty}\frac{1}{1-\beta^*}x_{t+j}\right] = -N_{CF,t} + N_{DR,t} + \boldsymbol{e}_1'\boldsymbol{u}_t
\end{aligned}$$

[Figure 5 about here.]

We need an estimate of β^* to decompose the FX news. We can identify β^* from the immediate response of the log exchange rate to a basis shock purged of the cumulative effect on the cash flow component:

$$\frac{1}{1-\beta^*} = -\frac{\Delta q_t - \mathbb{E}_t \sum_{\tau=0}^{\infty} \Delta i_{t+\tau}}{\mathbb{E}_t \sum_{\tau=0}^{\infty} \Delta x_{t+\tau}},$$

where Δ denotes the response to an orthogonalized basis shock. This orthogonalization is discussed in detail in section 3.4. Our identifying assumption is that the discount rate component does not respond to the basis shock (see section B of the separate Appendix for details).

Figure 5 plots the dollar's news about convenience yields against the news about the dollar exchange rate. The light-shaded areas include the ERM crisis, the Gulf war, the Russian default and LTCM crisis and the recent global financial crisis. Most of the variation in CY news arises during periods of increased global uncertainty and during crises. During global crisis episodes, the CY news induces an appreciation of the USD during global financial crises, when global investors seek the safety of the USD safe assets. During the recent crisis, CY news induced an appreciation of 15% of the USD. However, these effects are largely transitory, given that the basis quickly reverts back to its mean. The correlation between the CY news and the exchange rate innovations is 0.40 at quarterly frequencies.

[Figure 6 about here.]

While the convenience yield component is clearly tied to global crises, the cash flow and discount rate news seem more related to the U.S. business cycle. Figure 6 plots the cash flow news against the news about the dollar exchange rate. The dark-shaded areas indicate NBER recessions. The cash flow news component of the dollar is clearly pro-cyclical. At the start of NBER recessions, US yields decline relative to foreign yields, thus contributing to a weakening of the dollar. Finally, Figure 7 plots the discount rate news, which is pro-cyclical. At the start of NBER recessions, the risk premium on the dollar declines, contributing to a strengthening of the dollar. The DR news is only weakly correlated with the dollar innovations.

[Figure 7 about here.]

Panel A of Table 5 presents the variance decomposition of quarterly dollar exchange rate innovations for the panel of countries. For the panel, we identify a larger β^* of 0.97. As a result, we see that convenience yield news (CY) accounts for 33% of the variance in quarterly exchange rates. This number increases to 81% if we adjust $\beta^*$for the initial momentum effect. Interest rate news (CF) accounts for only a small component (13%) of the variance, while risk premium news (DR) accounts for a sizable component of 157%.[19] These results are highly dependent on β^*. A lower parameter value results in lower fractions of the variance attributable to CY news. Panel B reports the results for the U.S./U.K. We identify a smaller β^* of 0.93. Nevertheless, news about the convenience yields still accounts for 49% (91% when correcting for the momentum effect) of the exchange rate news, compared to 58% for the cash flow component.

[Table 5 about here.]

3.4 The Dollar's Impulse Response to U.S. Treasury Basis Shocks

This section identifies structural basis shocks that are uncorrelated with other shocks, and traces out the dynamic response of exchange rates and interest rates to these innovations. We use a Vector Autoregression (VAR) to model 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 this exercise, we define the 12-month US real interest rate $r_t^{\$}$ as $y_t^{\$} - \pi_{t\to t+4}^{\$}$. The foreign real interest rate is similarly defined as $y_t^* - \pi_{t\to t+4}^*$. For the panel, we run a VAR with three variables: the basis, the real interest rate difference, and the log of the real exchange rate $\overline{x}_t^{Treas}$, $r_t^{\$} - \overline{r}_t^*$, and $\overline{q}_t$. The VAR includes one lag of all variables. We identified the VAR(1) as the optimal specification using the BIC. This specification assumes that the log of the real U.S. 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 interest rate affect the exchange rate and the interest rate differential but not the basis, and shocks to the exchange rate only affect itself. This ordering implies that nominal and real exchange rates can respond instantaneously to all of the structural shocks. As we discuss, the evidence from the VAR provides support for interpreting our regression evidence causally: shocks to convenience yields drive movements in the exchange rate.

[19] Note that the numbers in each row add up to 100% because shocks to these news components may be negatively correlated.

[Figure 8 about here.]

Figure 8 plots the impulse response from orthogonalized shocks to the basis. The top left panel plots the dynamic behavior of the basis (in units of percentage points), the top right panel plots the dynamic behavior of the interest rate difference (in percentage points), and the bottom left panel plots the behavior of the exchange rate (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 real exchange rate contemporaneously by about 4% over two quarters. The finding that the depreciation persists over 2 quarters is consistent with the time-series momentum effect discussed earlier. Thus, the exchange rate exhibits classic Dornbusch (1976) overshooting behavior. Then there is a gradual reversal over the next 5 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. Finally, the bottom right panel plots the quarterly log excess return on a long position in dollars. Initially, the quarterly excess return drops, but after the first 2 quarters, it is higher than average for the next 15 to 18 quarters, consistent with higher expected returns on long positions in Treasurys.

Interestingly, once you add the basis shock, U.I.P. roughly holds for the dollar against this panel of currencies. Figure 9 plots the response to the interest rate shocks. The dollar appreciates in real terms in the same quarter by more than 100 basis points in response to a 100 bps increase in the U.S. yields above the foreign yields.[20] The bottom right panel of the figure plots the excess return on the currency, and we see that this return is zero after the first quarter indicating that U.I.P. holds once we account for shocks to the basis.

[Figure 9 about here.]

Basis shocks account for a large fraction of the exchange rate forecast error variance, especially at longer horizons (see Separate Online Appendix). At the one-quarter horizon, basis shocks account for more than 20% of the variance; this fraction increases to 60% at longer horizons. In contrast, the interest rate shocks account for less than 15% at all horizons. While the initial impact of a one-standard deviation interest rate shock on the dollar is similar to that of a one-standard deviation basis shock (roughly 2%), its effect does not initially build up and is much less persistent.[21]

[20] Recently, Engel (2016) and Dahlquist and Penasse (2016) have documented that an increase in the short-term US interest rate initially causes the dollar to appreciate, but they subsequently depreciate on average. Once we allow for shocks to the basis, the initial appreciation effect disappears.

[21] Figure A.1 in Section C of the Separate Appendix reports all of the impulse responses.

Importantly, the results are not sensitive to switching the order of the basis and interest rate differential, indicating that we can plausibly interpret the relation between the basis and exchange rate causally: A shock to convenience yields moves both the basis and the exchange rate. We say this because we have allowed for other known determinants of the exchange rate, relative price levels and relative interest rates, and yet recover the same relation between the basis and the exchange rate.[22]

We report the estimated impulse responses for the US/UK in the separate appendix. The variables included in the VAR are the basis, the interest rate differential and the log of the real exchange rate (GBP-per-USD). The impulse response patterns in this figure are similar to those documented in Figure 8, but have smaller magnitudes and are less persistent. An increase in the basis of 40 basis points leads to a real depreciation in the dollar against the pound of about 1.8% over two quarters. Then, the effect gradually reverses out over 3 years. We also report the impulse responses that obtain when we switch the ordering of the interest rate differences and the basis. The responses to the basis shock again look identical.[23]

3.5 The Treasury Basis and Dollar Safe Asset Demand

We have argued that a specific form of capital flows consisting of safe dollar assets drives the value of the US dollar. To close this section, we further explain why our evidence supports this interpretation.

First, we construct the basis from the safest asset, the US Treasury bond, and document a relation between this basis and the dollar. Second, our estimates imply a value of β^* in the range of 0.65 to 0.95. That is, foreign investors also have a convenience demand for dollar LIBOR bank deposits. In the pre-crisis sample, bank arbitrage meant that the forward price also reflected this convenience demand so that the LIBOR basis was near zero. However, in the post-crisis sample, the existence of bank arbitrage constraints allows convenience demand to be reflected in the LIBOR basis. We have shown in this sample that the LIBOR basis has explanatory power in the post-crisis sample, consistent with the broad dollar safe asset demand theory. Third, we compute a KfW bond basis in the separate Online Appendix. KfW is a German issuer whose bonds are backed by the

[22]Figure A.2 in the Separate Appendix switches the ordering of the interest rate difference and the basis in the VAR. The impulse responses to a basis shock are nearly identical to those of Figure 9. The exchange rate falls a little under 4% over two quarters and then gradually reverts over the subsequent 2 years. Note that our finding that ordering does not matter need not have been the result. It occurs simply because the reduced form VAR innovations to the basis and the interest rate difference are only weakly correlated. Finally, the variance decomposition also looks independent of ordering.

[23]Finally, we also adopted a local projection approach by projecting returns $rx_{t+k-1\to t+k}$ on $\left[\overline{x}_t, r_t^{\$} - \overline{r}_t^*, q_t\right]$ and $[\Delta\overline{x}_t, \Delta\overline{x}_{t-1}]$. These yield impulse responses that are quite similar to the ones produced by the Cholesky decomposition. The results are not reported.

German government, so that they are near default free. KfW issues bonds in different currencies allowing us to compute the basis for the bonds of the same issuer, i.e., holding safety fixed, in different currencies.[24] The KfW and the Treasury bases have roughly the same magnitude and track each other closely. This evidence also indicates that foreign investors' demand is for safe KfW bonds denominated in U.S. dollars. Fourth, in the Online Appendix, we perform a placebo test of safe asset demand. We repeat the univariate regression of Table 3, column (1), but using other non-U.S. countries as the base country. We find that the negative association between the exchange rate movement and Treasury basis is a phenomenon that is particularly strong for the U.S. where we posit that these safe asset demand effects should be most pronounced. For other countries the regression coefficients are largely statistically insignificant and/or the R^2 are considerably lower than the U.S. regressions.

4 Predictability of Exchange Rates and Excess Returns

We turn to the second implication of Proposition 1, which can be read as a forecasting regression. A more negative x_t (high λ_t^*) today means that today's dollar exchange rate appreciates, which induces an expected depreciation over the next period. We define the annualized log excess return as $rx_{t\to t+k} = \frac{4}{k}\left(\Delta s_{t\to t+k}\right) + \left(y_t^{\$} - \overline{y}_t^*\right)$ Note that the LHS of equation (22) is akin to the return on the reverse currency carry trade. 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 term (RP), and following the literature, a proxy for this risk premium is the rate differential across the countries. Thus we include the mean Treasury yield differential at each date as a control in our regression. Additionally as we have shown in Table 3, there is a slow adjustment to basis shocks, as given by the lag of $\Delta\overline{x}_t^{Treas}$, which we also include in our regression.

We project future excess returns $rx_{t\to t+k}$ on the average Treasury basis, $\overline{x}^{Treas}$, the nominal Treasury yield difference $(y^{\$} - y^*)$ and the change in the average Treasury basis from $t-1$ to t, as well as the lagged change in the Treasury basis (from $t-2$ to $t-1$):

$$rx_{t\to t+k} = \alpha^k + \beta_x^k \overline{x}_t^{Treas} + \beta_y^k (y_t^{\$} - \overline{y}_t^*) + \beta_L^k \Delta\overline{x}_t^{Treas} + \gamma_L^k \Delta\overline{x}_{t-1}^{Treas} + \epsilon_{t+k}^k$$

[24]We compute the basis for KfW bonds using one-year yields on these bonds for Australia, Euro, UK, and Switzerland against the US.

Our theory suggests that the coefficient β_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 6 reports the results obtained when forecasting the annualized excess returns on a long position in the dollar. We project future excess returns $rx_{t \to t+k}$ on the average Treasury basis, $\overline{x}^{Treas}$, the nominal Treasury yield difference $(y^{\$} - y^{*})$ and the change in the average Treasury basis, as well as the lagged change in the Treasury basis. Panel A reports the regression results for the entire sample.

[Table 6 about here.]

The slope coefficient on the average basis β_x^k varies from -16.76 at the 3-month horizon to 8.12 at the 3-year horizon. A one-standard-deviation negative shock to the basis of 20 bps increases the expected excess returns by 3.35% per annum over the first 3 months, as the dollar continues to appreciate for another quarter. However, this basis-induced momentum effect is short-lived and the slope coefficient switches signs over longer holding periods. The long-horizon estimates are an accurate reflection of the basis effect after stripping away the momentum effect, as we discuss below. These effects are economically significant. A one-standard-deviation basis shock of 20 bps. raises the expected excess return by 1.62% per annum over the next three years. These regressors jointly explain about 12% of the variation in excess returns at the 3-year horizon. The basis is also not a persistent regressor. Hence, there is no mechanical relation between the forecasting horizon and the R^2.

From equation (10) we see that the value of $\frac{1}{1-\beta^*}$ is equal to β_x for the 1-year horizon, but the 1-year β_x for 1-year is small and imprecisely estimated, likely because of the momentum effect we have found. A lower bound for $1 - \beta^*$ is $\frac{1}{\beta_x}$ 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 $1 - \beta^*$ of 0.12. Panel B and C of Table 6 report the regression results for the pre-and post-crisis sample. The momentum effect is only present prior the crisis. In the post-crisis sample, the slope coefficients on the basis are all positive. At the 3-year horizon, the coefficient is 13.35: A one-standard-deviation basis shock raises the expected excess return by 2.67% per annum over the next three years. In the post-crisis sample, these regressors jointly explain about 35% of the joint variation in excess returns at the 3-year horizon.

Table 7 provides more detail for the 3-year forecasting results. Panel A reports the 3-year results. Panel B excludes the first four quarters from the cumulative excess return to remove the momentum effect. At the 3-year horizon, the slope coefficient in a univariate regression of returns on the basis is not statistically significantly different from zero. However, when we exclude the first 4 quarters from the left-hand-side return, the slope coefficient in the univariate regression increases from 1.62 to 6.54. The variation in the Treasury basis explains 7% of the variation in the returns at the 3-year horizon. Finally, we note that the return predictability is mostly driven by the exchange rate component of returns. Table A.14 and A.15 in section D.7 of the Separate Appendix shows predictability results for exchange rate changes.[25]

[Table 7 about here.]

The results for the US/UK Treasury basis are quite similar to those obtained on the shorter sample for the Panel. Table 8 reports the results obtained when forecasting the annualized excess returns on a long position in the dollar and a short position in the pound. Panel A considers the results obtained on the entire sample. At short horizons of 3 months, the slope coefficient on the Treasury basis is negative (-2.01). On the other hand, at horizons of 3 years, the slope coefficient is positive and statistically significant: 7.15. This is a quantitatively significant response as well: a one-standard-deviation shock to the U.S./U.K. Treasury basis increases the 3-year return by 2.78%. These regressors jointly explain 28% of the variation in the 3-year excess returns. Panel B and C report results for the pre-and post-crisis sample. The slope coefficients at the 3-year horizon vary from 7.11 in the pre-crisis sample to 8.80 in the post-crisis sample. As was the case in the Panel data, there is no evidence of a basis-induced momentum effect post-crisis: all of the coefficient estimates for the US/UK Treasury basis are positive at all forecasting horizons. At the 3-month horizon, these variables jointly explain 54% in the post-crisis sample.

[Table 8 about here.]

Table 9 provides more detail by reporting results for each subsample. Panel A examines the 3-year excess returns. Panel B excludes the first year. As was the case for the Panel, excluding the first year increases the size

[25] After excluding the first year, there is solid statistical evidence that the average Treasury basis forecasts changes in exchange rates: the slope coefficient estimate is 11.24, implying that the dollar appreciates by 2.24 % per annum over the next 3 years following a one-standard-deviation widening of average Treasury basis. When we add the other regressors, the R^2 increases to 15% over the entire sample. The slope coefficient on the Treasury basis increases to 13.01. A one-standard-deviation positive basis shock raises the expected excess return by 2.60% per annum over the next three years. The coefficient estimates reported in Panel B after cleansing the cumulative returns of the momentum effect are remarkably stable across subsamples.

of the slope coefficient. The univariate slope coefficient on the U.S./U.K. increases from 2.86 to 9.18. When we include the other regressors, the slope coefficient changes from 7.15 to 13.84. This coefficient estimate implies that a one-standard-deviation shock to the Treasury basis increases the expected excess return by 5.39% per annum over the next 3 years.

[Table 9 about here.]

We next ask whether these results hold out-of-sample, which has been an important issue in international finance.[26] All of the results in Tables 6 through 9 are based on regressions that use the full sample. We investigate whether there is economically significant out-of-sample predictability that is robust to parameter instability by considering trading strategies that exploit variation in the Treasury basis. We calculate the historic average of the Treasury basis between quarter $t-N$ and quarter $t-1$. We consider values of N of 4, 10, or 20 quarters. We then compute the profits from a trading strategy where we buy the U.S. dollar against the basket of other currencies in quarter t when the Treasury basis is higher than this historic average, i.e. when the U.S. Treasury convenience yield is lower. We short the U.S. dollar otherwise. We compute the profits when holding this position for a quarter and then rebalancing the position in the next quarter. If the convenience yield contains information for future exchange rate changes, this trading strategy will earn abnormal profits. Since the trading strategy is based only on information available at time t, the existence of abnormal profits is an out-of-sample confirmation of our convenience yield theory.

[Table 10 about here.]

Table 10 reports the results, with Panel A for the short cross-country sample and Panel B for the long US/UK sample. In both samples, the unconditional trading strategy of going long the dollar earns slightly negative profits. The conditional strategy earns abnormal profits in all cases. Focusing on the results for $N = 10$, the Sharpe ratio is 0.12 in Panel A and 0.27 in Panel B. These numbers are comparable to the Sharpe

[26] One approach to answering this question follows Meese and Rogoff (1983). These authors ask whether exchange rate fundamentals outperform a random walk when forecasting future exchange rates, finding that the random walk always outperforms than the theory. We have explored the Meese-Rogoff approach in our sample and found mixed results: over some horizons the convenience yield beats the random walk out-of-sample, while in others it does not. Results are available upon request. This negative result is because the parameter estimates (but not their signs) are sample dependent and to pass the random walk test both the convenience yield must matter for exchange rates and the relation between the convenience yield and the exchange rate must be stable over time.

ratio on the carry trade strategy (see Lustig, Roussanov and Verdelhan (2014*b*)). Again, the results in Panel B, with the longer sample, are stronger than those of Panel A.

[Table 11 about here.]

Finally, our theory posits a special role for the dollar. There is empirical evidence to support the notion that the dollar is different from other currencies. The dollar carry trade which goes long in a basket of foreign currencies when the foreign-minus-US interest rate gap is positive is highly profitable (Lustig, Roussanov and Verdelhan, 2014*a*), but this trade is not profitable for other currencies (Hassan and Mano, 2014). Our theory predicts that, all else equal, a widening of the dollar basis, is accompanied by an increase in the risk premium that U.S. investors demand on a long position in foreign currency. However, the dollar continues to appreciate for at least another quarter after the widening of the basis. Since the dollar Treasury basis typically widens when the interest rate gap $y^{\$} - y^{*}$ increases, this could help explain the profitability of the dollar carry trade.

5 Conclusion

We present a convenience yield theory of exchange rates which departs from existing theories by imputing a central role to international flows in Treasury debt and related dollar safe asset markets in exchange rate determination. Under our theory the spot exchange rate of a safe asset currency will reflect the cumulative value of all future convenience yields. Empirical evidence strongly supports the theory. Our results shed light on two important topics in international finance. First, we help to resolve the exchange rate disconnect puzzle by demonstrating both theoretically and empirically that the demand for safe assets drives a sizeable portion of the variation in the dollar exchange rate. Second, we provide strong empirical support for recent theories regarding safe assets and the central role of the U.S. in the international monetary system.

Prior evidence for the special role of the US dollar in safe debt markets comes from quantity evidence based on non-government borrowings and investments.[27] This evidence does not pin down whether it is investors that especially want to own dollar assets, driving down the cost of borrowing in dollars and hence incentivizing firms

[27] On the one hand, non-US borrowers tilt the denomination of their borrowings (loans, deposits, bonds) especially towards the US dollar. See Shin (2012) and Ivashina, Scharfstein and Stein (2015) on bank borrowing, Bräuning and Ivashina (2017) on loan denomination, and Bruno and Shin (2017) on corporate bond borrowing. On the other hand, there is also evidence that when foreign investors hold corporate bonds in currencies other than their own, they tilt their portfolios toward owning US dollar corporate bonds (see Maggiori, Neiman and Schreger (2017)).

and banks to borrow in dollars, or whether it is the reverse. That is, firms and banks especially want to borrow in dollars, are willing to pay higher returns on borrowing in dollars and hence attracting dollar international investors. Prices help resolve the issue. Our evidence is in favor of the former explanation, i.e., there is a special demand for US dollar safe assets driving down yields on these assets. The Treasury dollar basis is negative and declines in the Treasury basis cause the dollar to appreciate.

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Table 1: Summary Statistics of Cross-sectional Mean Basis and Interest Rate Difference

Table reports summary statistics in percentage points for the 12-M Treasury dollar basis $\overline{x}^{Treas}$, the Libor dollar basis $\overline{x}^{Libor}$, the 12M yield spread $y^{\$} - \overline{y^{*}}$, and the 12M forward discount $\overline{f - s}$ in logs. Table reports time-series averages, time-series standard deviations and correlations. Numbers reported are time-series moments of the cross-sectional means of the unbalanced Panel. 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. For each of these cross-sectional averages, we employ the same set of countries that are in the sample at time t.

	$\overline{x}^{Treas}$	$\overline{x}^{Libor}$	$y^{\$} - \overline{y^{*}}$	$\overline{f - s}$
	Panel A: 1988Q1−2017Q2			
mean	-0.25	-0.07	-0.45	-0.20
stdev	0.24	0.18	1.87	1.95
skew	-1.33	-3.08	-0.61	-0.29
x^{Treas}	1.00	0.36	-0.27	-0.39
x^{Libor}	0.36	1.00	0.47	0.40
$y^{US} - y^{*}$	-0.27	0.47	1.00	0.99
	Panel B: 1988Q1−2007Q4			
mean	-0.27	-0.04	-0.33	-0.05
stdev	0.26	0.16	2.25	2.34
skew	-0.93	-4.62	-0.69	-0.42
x^{Treas}	1.00	0.34	-0.31	-0.41
x^{Libor}	0.34	1.00	0.54	0.48
$y^{US} - y^{*}$	-0.31	0.54	1.00	0.99
	Panel C: 2008Q1−2017Q2			
mean	-0.20	-0.13	-0.64	-0.44
stdev	0.21	0.20	0.78	0.80
skew	-2.51	-1.78	0.16	0.09
x^{Treas}	1.00	0.56	0.00	-0.25
x^{Libor}	0.56	1.00	0.51	0.35
$y^{US} - y^{*}$	0.00	0.51	1.00	0.97

Table 2: The Treasury Basis and Interest Rate Spreads

We regress the quarterly average Treasury basis, $\overline{x}^{Treas}$, 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.

	(1)	(2)	(3)	(4)	(5)	(6)
US 6-month OIS−T-bill	0.13					
	(0.18)					
US 6-month LIBOR−OIS		-0.40			-0.44	
		(0.034)			(0.027)	
US 6-month LIBOR−T-bill			-0.47			-0.43
			(0.045)			(0.044)
$y^{\$} - \overline{y}^{*}$				-0.047	-0.07	-0.029
				(0.01)	(0.01)	(0.007)
R^2	1%	69.5	48	16.7	82.9	54
N	63	63	118	118	63	118

Table 3: Average Treasury Basis and the USD Spot Nominal 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, $\Delta\overline{x}^{Treas}$, as log yield (i.e. 50 basis points is 0.005), the lagged value of the innovation, the innovation in the LIBOR basis, and the innovation in the US-to-foreign Treasury yield differential. Data is quarterly. OLS standard errors in parentheses.

	1988Q1−2017Q2					1988Q1−2007Q4		2008Q1−2017Q2	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
$\Delta\bar{x}^{Treas}$	-9.62		-9.70		-9.30	-8.52		-12.93	
	(2.05)		(1.95)		(1.70)	(2.58)		(3.18)	
$\Delta\bar{x}^{LIBOR}$		-2.48					2.79		-10.05
		(3.05)					(4.19)		(3.98)
Lag $\Delta\bar{x}^{Treas}$			-6.65		-6.21				
			(1.94)		(1.69)				
$\Delta(y^{\$} - \bar{y}^{*})$				3.80	3.59				
				(0.70)	(0.59)				
R^2	16.1	0.6	23.5	20.4	42.4	12.2	0.6	32.1	15.4
N	117	117	116	117	116	80	80	37	37

Table 4: US/UK Treasury Basis and the Spot Real Exchange Rate

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

	1970Q1 - 2016Q2			1980Q1 - 2016Q2	1990Q1 - 2016Q2
	(1)	(2)	(3)	(4)	(5)
$\Delta\overline{x}^{Treas}$	-1.77		-1.74	-3.40	-11.67
	(0.78)		(0.77)	(1.57)	(2.40)
Lag $\Delta\overline{x}^{Treas}$	-1.70		-1.69	-4.59	-3.89
	(0.78)		(0.77)	(1.52)	(2.36)
$\Delta(y^{\$} - \overline{y}^{UK})$		0.13	0.13		
		(0.08)	(0.08)		
R^2	5.0	1.6	6.5	10.3	28.4
N	183	185	183	144	104

Table 5: News Decomposition of Real Exchange Rates Innovations

Panel A reports the decomposition of quarterly innovations in log of average USD real exchange rate in the Panel. The VAR is estimated using a sample from 1988Q1 to 2017Q2. The VAR(1) includes $\left[\overline{x}_t, r_t^{\$} - \overline{r}_t^*, q_t\right]$. The first row uses the point estimate for $1-\beta^*$ (in italics) of 0.031. Panel B reports the decomposition of quarterly innovations in log of GBP/USD. The VAR is estimated using a sample from 1970Q1 to 2016Q2. The VAR(1) includes $\left[x_t, r_t^{\$} - r_t^*, q_t\right]$. The first row uses the point estimate for $1-\beta^*$ (in italics) is 0.071. The point estimate for $1-\beta^*$ in italics is identified from the impulse response to an orthogonal basis shock: $\frac{1}{1-\beta^*} = \frac{\Delta s_t^{real} - \Delta\mathbb{E}_t \sum_{\tau=0}^{\infty}(r_{t+\tau}^{\$} - r_{t+\tau}^*)}{\Delta\mathbb{E}_t \sum_{\tau=0}^{\infty} x_{t+\tau}}$ a VAR with ordering is $\left[\overline{x}_t, r_t^{\$} - \overline{r}_t^*, q_t\right]$. The second row corrects for the momentum effect by substituting $\min_k \Delta s_{t\to t+k}^{real}$ for Δs_t^{real} in this equation.

$1-\beta^*$	$1/(1-\beta^*)$	var(CY)	var(CF)	var(DR)	2cov(CY,CF)	-2cov(CY,DR)	-2cov(CF,DR)
			Panel A: Panel Data				
0.031	32.67	0.33	0.13	1.57	0.18	-0.92	-0.29
0.019	51.53	0.81	0.13	2.21	0.29	-2.05	-0.40
			Panel B: US/UK				
0.071	14.01	0.49	0.58	2.30	0.47	-1.12	-1.71
0.052	19.18	0.91	0.58	2.78	0.65	-2.03	-1.88

Table 6: Forecasting Currency Excess Returns in Panel Data

The dependent variable is the annualized nominal excess return (in logs) $rx^{fx}_{t\to t+k}$ on a long position in U.S. Treasuries and a short position (equal-weighted) in all foreign bonds over k quarters. The independent variables are the average Treasury basis, $\overline{x}^{Treas}$, the nominal Treasury yield difference $(y^{\$} - y^{*})$, the change in the average Treasury basis $\Delta\overline{x}^{Treas}_t$ from $t-1$ to t, and a lag of the change in the average Treasury basis $\Delta\overline{x}^{Treas}_{t-1}$. Data is quarterly from 1988Q1 to 2017Q2. Heteroskedasticity and autocorrelation adjusted standard errors in parentheses.

	$\overline{x}^{Treas}$	$y^{\$} - \overline{y}^{*}$	$\Delta\overline{x}^{Treas}$	Lag $\Delta\overline{x}^{Treas}$	R^2
			Panel A: 1988-2017		
3 months	-16.76	-0.17	-7.96	2.80	0.08
	(13.15)	(1.36)	(10.29)	(10.25)	
1 year	-0.63	0.28	-7.46	-2.93	0.04
	(8.72)	(0.96)	(5.64)	(3.93)	
2 years	4.72	0.35	-7.65	-5.24	0.05
	(5.07)	(0.58)	(3.27)	(2.48)	
3 years	8.12	0.49	-8.45	-5.22	0.12
	(3.99)	(0.39)	(2.74)	(2.07)	
			Panel B: 1988-2007		
3 months	-30.66	-0.37	5.79	14.55	0.13
	(15.04)	(1.47)	(9.51)	(10.52)	
1 year	-10.23	0.16	-5.55	-3.70	0.13
	(9.63)	(0.92)	(7.00)	(5.21)	
2 years	-2.33	0.18	-4.41	-4.31	0.06
	(5.51)	(0.56)	(4.12)	(3.04)	
3 years	5.14	0.42	-8.11	-5.50	0.09
	(4.83)	(0.37)	(3.50)	(2.51)	
			Panel C: 2007-2017		
3 months	17.94	-3.58	-32.05	-29.41	0.21
	(10.92)	(3.04)	(11.78)	(10.40)	
1 year	18.56	-2.41	-6.44	-3.43	0.22
	(7.11)	(2.57)	(6.19)	(3.27)	
2 years	20.71	0.35	-13.35	-9.06	0.46
	(3.47)	(0.82)	(2.21)	(2.22)	
3 years	13.87	0.24	-7.72	-5.73	0.33
	(3.21)	(0.76)	(2.10)	(1.58)	

Table 7: Forecasting 3-year Currency Excess Returns in Panel Data

In Panel A (B), the dependent variable is the annualized nominal excess return (in logs) $rx^{fx}_{t\to t+12}$ ($rx^{fx}_{t+4\to t+12}$) on a long position in U.S. Treasuries and a short position (equal-weighted) in all foreign bonds over k quarters. The independent variables are the Treasury basis, x^{Treas}, the nominal Treasury yield difference ($y^{\$} - y^{*}$), the change in the Treasury basis $\Delta\overline{x}^{Treas}_{t}$ from $t-1$ to t, and a lag of the change in the Treasury basis $\Delta\overline{x}^{Treas}_{t-1}$. Data is quarterly from 1988Q1 to 2017Q2. Heteroskedasticity and autocorrelation adjusted standard errors in parentheses.

	$\overline{x}^{Treas}$	$y^{\$}-\overline{y}^{*}$	$\Delta\overline{x}^{Treas}$	Lag $\Delta\overline{x}^{Treas}$	R^2	$\overline{x}^{Treas}$	$y^{\$}-\overline{y}^{*}$	$\Delta\overline{x}^{Treas}$	Lag $\Delta\overline{x}^{Treas}$	R^2
	Panel A: $rx^{fx}_{t\to t+12}$					*Panel B:* $rx^{fx}_{t+4\to t+12}$				
1988-2017	1.62				0.01	6.54				0.07
	(2.47)					(2.82)				
	2.26	0.30			0.02	7.12	0.27			0.07
	(2.46)	(0.33)				(2.63)	(0.33)			
	5.34	0.40	-5.38		0.07	9.89	0.45	-5.69		0.10
	(3.22)	(0.35)	(1.82)			(3.60)	(0.32)	(2.37)		
	8.12	0.49	-8.45	-5.22	0.12	13.01	0.61	-9.42	-6.75	0.15
	(3.99)	(0.39)	(2.74)	(2.07)		(4.60)	(0.34)	(3.70)	(2.84)	
1988-2007	-1.17				0.00	6.53				0.06
	(2.96)					(3.11)				
	-0.49	0.25			0.01	7.21	0.25			0.07
	(2.93)	(0.31)				(2.98)	(0.32)			
	2.30	0.33	-4.48		0.04	9.97	0.41	-5.38		0.09
	(3.98)	(0.33)	(2.22)			(4.25)	(0.33)	(2.90)		
	5.14	0.42	-8.11	-5.50	0.09	12.82	0.55	-9.38	-6.40	0.13
	(4.83)	(0.37)	(3.50)	(2.51)		(5.55)	(0.35)	(4.83)	(3.55)	
2007-2017	8.17				0.20	5.73				0.06
	(2.80)					(3.09)				
	8.17	-0.17			0.20	5.70	1.13			0.09
	(2.82)	(0.62)				(3.23)	(1.30)			
	10.67	0.03	-5.65		0.27	8.50	1.34	-6.33		0.14
	(2.88)	(0.71)	(2.21)			(3.22)	(1.33)	(2.56)		
	13.87	0.24	-7.72	-5.73	0.33	12.89	1.63	-9.16	-7.84	0.22
	(3.21)	(0.76)	(2.10)	(1.58)		(3.59)	(1.33)	(2.29)	(2.23)	

Table 8: Forecasting Currency Excess Returns: US/UK

The dependent variable is the annualized nominal excess return (in logs) $rx^{fx}_{t\to t+k}$ on a long position in U.S. Treasuries and a short position (equal-weighted) in U.K. bonds over k quarters. The independent variables are the Treasury basis, x^{Treas}, the nominal Treasury yield difference $(y^{\$}-y^{*})$, the change in the Treasury basis Δx^{Treas}_t from $t-1$ to t, and a lag of the change in the Treasury basis Δx^{Treas}_{t-1}. Heteroskedasticity and autocorrelation adjusted standard errors in parentheses. Data is quarterly from 1970Q1 to 2017Q2.

	x^{Treas}	$y^{\$}-\overline{y}^{*}$	Δx^{Treas}	Lag Δx^{Treas}	R^2
			Panel A: 1970-2017		
3 months	-2.01	2.73	-6.08	-3.03	0.09
	(4.38)	(1.26)	(4.68)	(3.01)	
1 year	0.21	1.79	-3.28	-2.31	0.08
	(3.07)	(0.86)	(2.02)	(1.34)	
2 year	3.26	1.49	-5.40	-3.56	0.13
	(2.17)	(0.59)	(1.72)	(1.06)	
3 year	7.15	1.49	-6.64	-4.31	0.28
	(1.70)	(0.44)	(1.43)	(0.96)	
			Panel B: 1970-2007		
3 months	-2.54	3.09	-4.52	-2.34	0.11
	(4.54)	(1.33)	(4.55)	(2.94)	
1 year	-0.13	1.86	-3.26	-2.59	0.10
	(3.12)	(0.92)	(2.04)	(1.35)	
2 year	3.08	1.48	-5.23	-3.57	0.14
	(2.22)	(0.65)	(1.75)	(1.08)	
3 year	7.11	1.47	-6.61	-4.35	0.30
	(1.76)	(0.51)	(1.47)	(0.98)	
			Panel C: 2007-2017		
3 months	25.73	-8.84	-88.53	-28.34	0.54
	(11.39)	(2.88)	(20.56)	(16.67)	
1 year	22.48	-7.74	-1.24	9.75	0.42
	(7.66)	(2.56)	(7.17)	(7.78)	
2 year	10.89	-3.73	-9.13	3.99	0.30
	(12.09)	(1.48)	(9.12)	(7.33)	
3 year	8.80	-1.82	-4.48	0.57	0.20
	(6.90)	(0.86)	(5.29)	(3.78)	

Table 9: Forecasting 3-year Currency Excess Returns: US/UK

In Panel A (B), the dependent variable is the annualized nominal excess return (in logs) $rx^{fx}_{t\to t+12}$ ($rx^{fx}_{t+4\to t+12}$) on a long position in U.S. Treasuries and a short position (equal-weighted) in all foreign bonds over k quarters. The independent variables are the Treasury basis, x^{Treas}, the nominal Treasury yield difference ($y^{\$} - y^{*}$), the change in the Treasury basis Δx^{Treas}_t from $t-1$ to t, and a lag of the change in the Treasury basis Δx^{Treas}_{t-1}. Data is quarterly from 1970Q1 to 2017Q2. Heteroskedasticity and autocorrelation adjusted standard errors in parentheses.

	x^{Treas}	$y^{\$} - \overline{y}^{*}$	Δx^{Treas}	Lag Δx^{Treas}	R^2	x^{Treas}	$y^{\$} - \overline{y}^{*}$	Δx^{Treas}	Lag Δx^{Treas}	R^2
	Panel A: $rx^{fx}_{t\to t+12}$					*Panel B:* $rx^{fx}_{t+4\to t+12}$				
1970-2017	2.86				0.05	9.18				0.06
	(1.16)					(4.12)				
	2.99	1.19			0.14	9.28	0.89			0.06
	(1.07)	(0.48)				(4.16)	(0.89)			
	5.14	1.31	-4.04		0.21	12.08	1.07	-5.67		0.08
	(1.49)	(0.46)	(1.00)			(3.76)	(0.90)	(2.38)		
	7.15	1.49	-6.64	-4.31	0.28	13.84	1.26	-7.84	-4.08	0.09
	(1.70)	(0.44)	(1.43)	0.96		(3.70)	(0.91)	(2.84)	(1.91)	
1970-2007	2.85				0.05	9.68				0.07
	(1.17)					(4.23)				
	2.96	1.16			0.14	9.75	0.76			0.07
	(1.11)	(0.54)				(4.28)	(1.00)			
	5.09	1.28	-3.97		0.21	12.45	0.94	-5.44		0.09
	(1.54)	(0.53)	(1.01)			(3.85)	(1.01)	(2.44)		
	7.11	1.47	-6.61	-4.35	0.30	13.99	1.13	-7.36	-3.64	0.09
	(1.76)	(0.51)	(1.47)	0.98		(3.76)	(1.02)	(2.94)	(1.93)	
2007-2017	6.90				0.07	-19.12				0.05
	(4.52)					(10.64)				
	7.22	-2.06			0.18	-19.60	3.05			0.07
	(4.49)	(0.63)				(9.52)	(1.74)			
	9.11	-1.82	-4.64		0.20	-7.81	4.54	-28.89		0.14
	(5.74)	(0.83)	(4.54)			(8.00)	(1.76)	(13.37)		
	8.80	-1.82	-4.48	0.57	0.20	-3.29	4.62	-31.15	-8.57	0.15
	(6.90)	(0.86)	(5.29)	(3.78)		(13.58)	(1.77)	(12.36)	(15.73)	

Table 10: Performance of Treasury Basis FX Strategies

In each quarter, we go long in the U.S. dollar against the basket of other currencies when the Treasury basis is higher than its average in the past N quarters, and short the US dollar otherwise. Table reports the quarterly mean nominal exchange rate movement of the currencies we go long against the currencies we short in the portfolio, the quarterly mean excess return of the portfolio, and the quarterly Sharpe Ratio of this strategy. We also report the performance of the portfolio that always buys the U.S. dollar against the basket of other currencies. Standard errors in parentheses obtained from bootstrapping over 10,000 rounds. In each round, we resample excess returns and exchange rate movements with replacement.

Panel A: Panel			
Portfolio	Mean FX Δ (%)	Mean Excess Return (%)	Sharpe Ratio
Long Dollar	-0.20	-0.08	-0.02
	(0.44)	(0.44)	(0.09)
$N = 4$ qtrs	0.81	0.86	0.19
	(0.43)	(0.43)	(0.10)
$N = 10$ qtrs	0.51	0.56	0.12
	(0.45)	(0.44)	(0.10)
$N = 20$ qtrs	0.32	0.46	0.12
	(0.38)	(0.38)	(0.10)
Panel B: US/UK data			
Portfolio	Mean FX Δ (%)	Mean Excess Return (%)	Sharpe Ratio
Long Dollar	-0.29	0.01	0.00
	(0.32)	(0.33)	(0.07)
$N = 4$ qtrs	0.59	0.65	0.14
	(0.33)	(0.33)	(0.07)
$N = 10$ qtrs	1.18	1.20	0.27
	(0.34)	(0.34)	(0.07)
$N = 20$ qtrs	1.08	1.19	0.26
	(0.35)	(0.36)	(0.08)

Table 11: Explaining Performance of Treasury Basis FX Strategies

We regress the return of the conditional dollar portfolio whose look-back period is 4 quarters during each quarter on the carry factor during that quarter, the dollar factor during that quarter, and the Treasury basis at the start of that quarter. The carry factor is obtained from Lustig, Roussanov and Verdelhan (2011), and the dollar factor is the excess return of the US dollar against the equal-weighted portfolio of other currencies in our sample. In this table, all returns and bases are in percentage points.

	Panel A: Panel			*Panel B: US/UK data*		
	(1)	(2)	(3)	(4)	(5)	(6)
Treasury Basis		-4.31	-4.02		0.02	0.07
		(1.93)	(1.78)		(1.44)	(0.73)
Dollar Factor	-0.07	-0.03		0.03	0.03	
	(0.10)	(0.10)		(0.09)	(0.09)	
Carry Factor	0.04	0.08		-0.07	-0.07	
	(0.09)	(0.09)		(0.08)	(0.08)	
Constant	0.83	-0.24	-0.10	0.72	0.71	0.65
	(0.46)	(0.66)	(0.60)	(0.42)	(0.42)	(0.34)
R^2	0.61	5.27	4.41	0.62	0.62	0.01
N	105	105	113	126	126	181

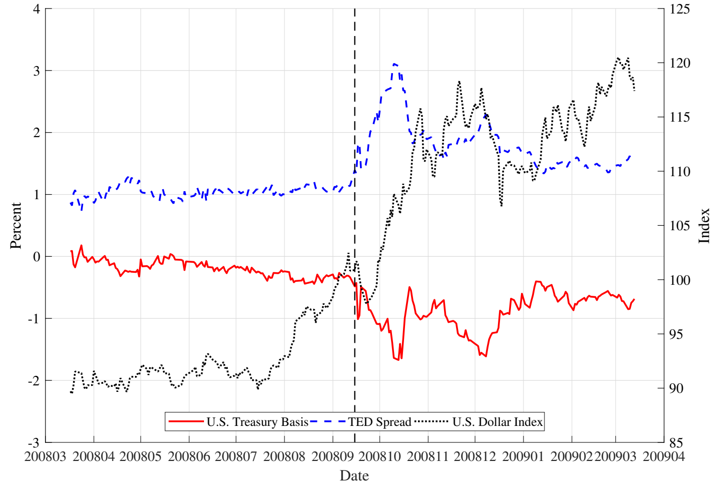

Figure 1: Failure of Lehman in Sept. 2008.

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 during the fall of 2008. We also graph the U.S. dollar exchange rate (black), measured against a basket of other currencies as well as the U.S. Treasury basis (red).

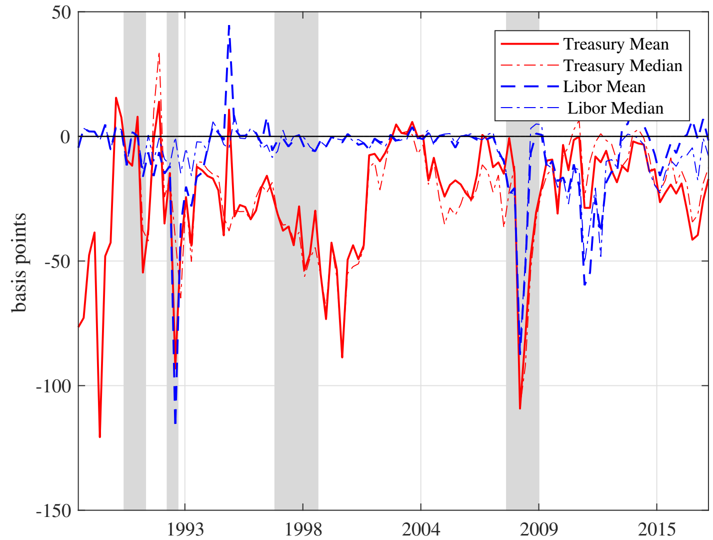

Figure 2: U.S. LIBOR and Treasury Bases

U.S. LIBOR and Treasury basis in basis points from 1988Q1 to 2017Q2. The maturity is one year. We plot the cross-sectional mean and median for each of the bases.

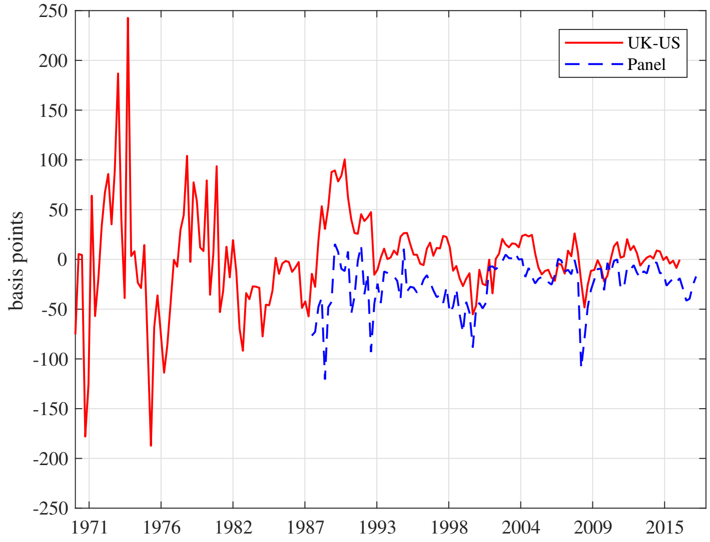

Figure 3: US/UK Treasury Basis

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.

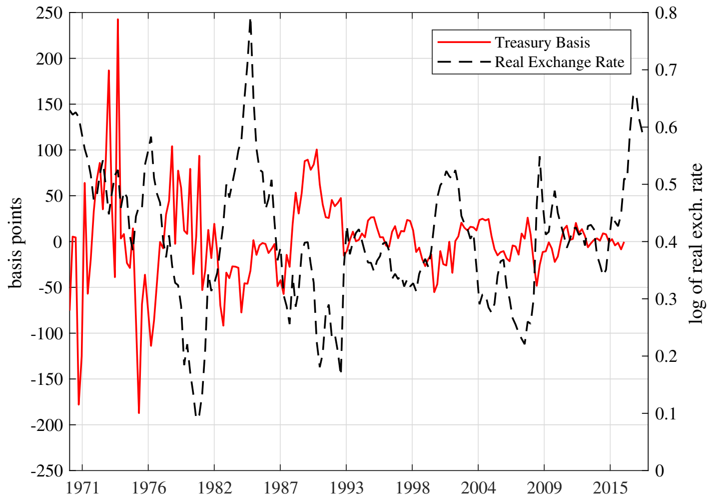

Figure 4: U.S./U.K. Treasury Bases and Real Exchange Rate

One-year maturity Treasury basis from 1970Q1 to 2017Q2 for US/UK, in basis points, and the log real US/UK exchange rate.

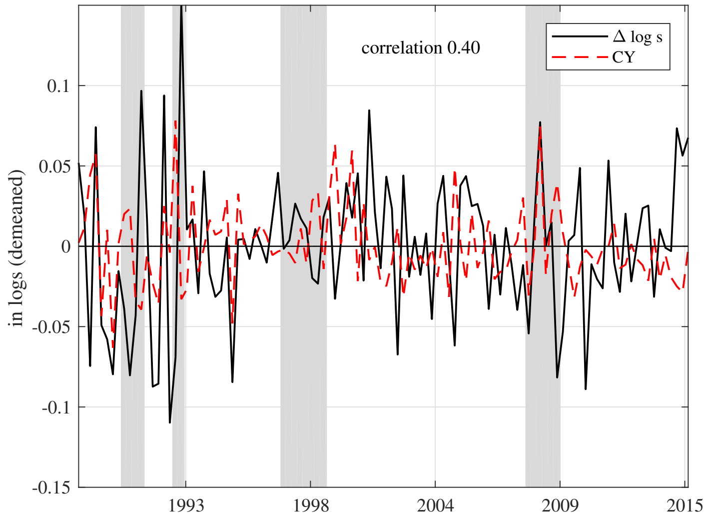

Figure 5: News about Convenience Yields

Plots quarterly news about convenience yields $N_{CY,t}$ against quarterly news about about exchange rates $\boldsymbol{e}_1'\boldsymbol{u}_t$ for the Panel. VAR is estimated using a sample from 1988Q1 to 2017Q2. The VAR(1) includes $\left[\overline{x}_t, r_t^{\$} - \overline{r}_t^*, q_t\right]$. β^* is 0.97. Shaded areas include the ERM crisis, the Gulf war, the Russian default and LTCM crisis and the recent global financial crisis.

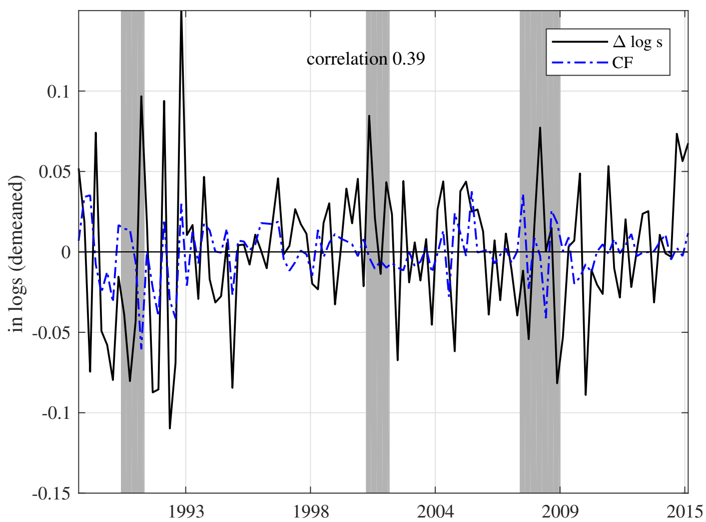

Figure 6: News about Cash Flows and Change in Real Exchange Rate

Plots quarterly news about convenience yields $N_{CY,t}$ against quarterly news about about exchange rates $\boldsymbol{e}_1'\boldsymbol{u}_t$ for the Panel. VAR is estimated using a sample from 1988Q1 to 2017Q2. The VAR(1) includes $\left[\overline{x}_t, r_t^{\$} - \overline{r}_t^*, q_t\right]$. β^* is 0.97. The shaded areas include NBER recessions.

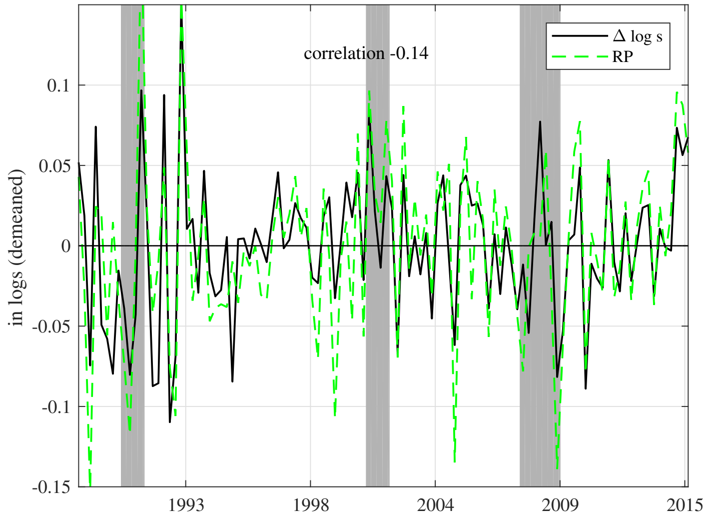

Figure 7: News about Risk Premia and Change in Real Exchange Rate

Plots quarterly news about convenience yields $N_{CY,t}$ against quarterly news about about exchange rates $\boldsymbol{e}_1'\boldsymbol{u}_t$ for the Panel. VAR is estimated using a sample from 1988Q1 to 2017Q2. The VAR(1) includes $\left[\overline{x}_t, r_t^{\$} - \overline{r}_t^*, q_t\right]$. β^* is 0.97. The shaded areas include NBER recessions.

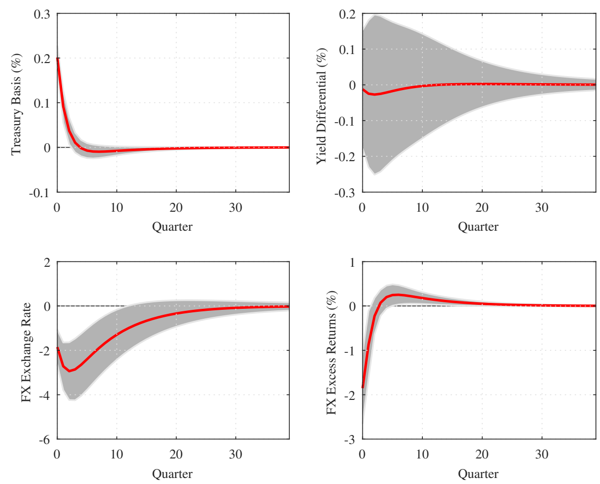

Figure 8: Dynamic Response to Treasury Basis Shocks: Panel.

The red line plots the impulse response of a one-standard-deviation orthogonalized shock to the average Treasury basis on the basis (top left panel), the real interest rate differential (top right panel), the log real spot exchange rate (bottom left panel), and the quarterly log excess return on a long position in dollars (bottom right panel). The units for the y-axis are in percentage points. The grey areas indicates 95% confidence intervals. Standard errors were generated using 10,000 Monte Carlo simulations. The VAR is estimated using a sample from 1988Q1 to 2017Q2. The ordering is $\left[\overline{x}_t, r_t^{\$} - \overline{r}_t^*, q_t\right]$.

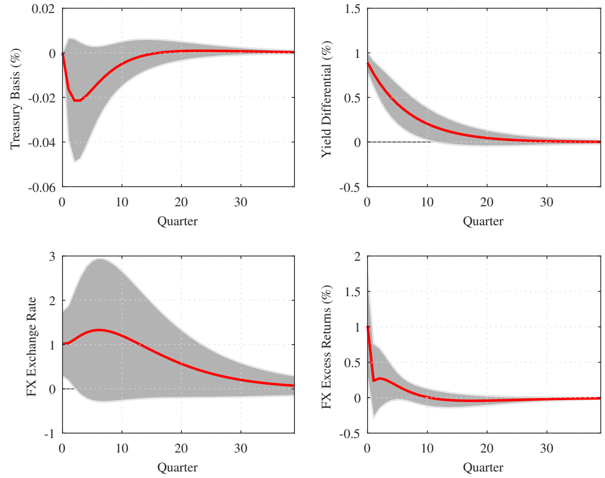

Figure 9: Dynamic Response to Rate Shocks: Panel.

The red line plots the impulse response of a one-standard-deviation orthogonalized shock to the yield difference on the basis (top left panel), the real interest rate differential (top right panel), the log real spot exchange rate (bottom left panel), and the quarterly log excess return on a long position in dollars (bottom right panel). The units for the y-axis are in percentage points. The grey areas indicates 95% confidence intervals. Standard errors were generated using 10,000 Monte Carlo simulations. The VAR is estimated using a sample from 1988Q1 to 2017Q2. The ordering is $\left[\overline{x}_t, r_t^{\$} - \overline{r}_t^{*}, q_t\right]$.

Appendix

A Theory of Convenience Yields and Exchange Rates

A.1 Convenience Yields in Complete Markets

We follow the approach of Backus, Foresi and Telmer (2001). Consider the Euler equations (3) and (8) 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,

$$M_t^{\$} \frac{S_t}{S_{t+1}} = M_t^*.$$

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:

$$\Delta s_{t+1} \quad = \quad m_t^{\$} - m_t^*. \tag{26}$$

Next consider the pair of Euler equations, (4) and (9), which apply to investments in the US bond that gives a convenience yield. We conjecture an exchange rate process that satisfies,

$$M_t^* e^{\lambda_t^*} \frac{S_{t+1}}{S_t} = M_t^{\$} e^{\lambda_t^{\$}}.$$

Log-linearizing this expression, we find:

$$\Delta s_{t+1} \quad = \quad \left(m_t^{\$} - m_t^*\right) + \left(\lambda_t^{\$} - \lambda_t^*\right) \tag{27}$$

It is evident that (26) and (27) cannot both be satisfied in an equilibrium unless $\lambda_t^* = \lambda_t^{\$}$. But note that in this case, convenience yields have no impact on exchange rates.

How is equilibrium restored when $\lambda_t^* \neq \lambda_t^{\$}$? 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. Alternatively, we could consider scenarios in which the U.S. Euler equation for foreign bonds does not hold for all investors. Suppose that the Euler equations for the U.S. 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. But note that even with such frictions, our equations linking foreign convenience yield valuations and the exchange rate remain valid.

A.2 Convenience Yields on Foreign Bonds

This section allows for a convenience yield on foreign bonds. We use $\lambda_t^{i,j}$ to denote the convenience yield of investors in country j for bonds issued by the government in country i. Similarly, $\beta^{i,j}\lambda_t^{i,j}$ is the convenience yield of investors in country j for LIBOR deposits in i's currency.

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

$$\mathbb{E}_t\left(M_{t+1}^* e^{y_t^*}\right) = e^{-\lambda^{*,*}}. \tag{28}$$

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,

$$\mathbb{E}_t\left(M_{t+1}^* \frac{S_{t+1}}{S_t} e^{y_t^\$}\right) = e^{-\lambda_t^{\$,*}}, \quad \lambda_t^* \geq 0. \tag{29}$$

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, (28) can be rewritten as,

$$\mathbb{E}_t\left(m_{t+1}^*\right) + \frac{1}{2} Var_t\left(m_{t+1}^*\right) + y_t^* + \lambda_t^{*,*} = 0, \tag{30}$$

and (29) as,

$$\mathbb{E}_t\left(m_{t+1}^*\right) + \frac{1}{2} Var_t\left(m_{t+1}^*\right) + \mathbb{E}_t[\Delta s_{t+1}] + \frac{1}{2} var_t[\Delta s_{t+1}] + y_t^\$ + \lambda_t^{\$,*} - RP_t^* = 0. \tag{31}$$

Here $RP_t^* = -cov_t\left(m_{t+1}^*, \Delta s_{t+1}\right)$ 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 in levels on a long position in dollars earned by a foreign investor is given by:

$$\mathbb{E}_t[\Delta s_{t+1}] + \left(y_t^\$ - y_t^*\right) + \frac{1}{2} var_t[\Delta s_{t+1}] = RP_t^* - \lambda_t^{\$,*} + \lambda_t^{*,*}. \tag{32}$$

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

$$\mathbb{E}_t\left(M_{t+1}^\$ \frac{S_t}{S_{t+1}} e^{y_t^*}\right) = e^{-\lambda_t^{*,\$}}. \tag{33}$$

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

$$\mathbb{E}_t\left(M_{t+1}^\$ e^{y_t^\$}\right) = e^{-\lambda_t^{\$,\$}}. \quad \lambda_t^{\$,\$} \geq 0. \tag{34}$$

$\lambda_t^\$$ is asset-specific. An increase in the U.S. investor's convenience yield lowers U.S. Treasury bond yields, holding the SDF fixed:

$y_t^{\$} = \rho_t^{\$} - \lambda_t^{\$,\$}$, where $\rho_t^{\$} = -\log \mathbb{E}_t \left(M_{t+1}^{\$} \right)$.

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

$$\left(y_t^* - y_t^{\$} \right) - \mathbb{E}_t[\Delta s_{t+1}] + \frac{1}{2} var_t[\Delta s_{t+1}] = RP_t^{\$} - \lambda_t^{*,\$} + \lambda_t^{\$,\$}. \tag{35}$$

where, $RP_t^{\$} = -cov_t \left(m_{t+1}^{\$}, -\Delta s_{t+1} \right)$ 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 (32) and (35) to derive a cross-country restriction on the convenience yields imputed to Treasurys and the currency risk premia,

$$(\lambda_t^{\$,*} - \lambda_t^{*,*}) - (\lambda_t^{\$,\$} - \lambda_t^{*,\$}) = RP_t^{\$} + RP_t^* - var_t[\Delta s_{t+1}]. \tag{36}$$

By forward iteration on eqn. (32), 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):

$$s_t = \mathbb{E}_t \sum_{\tau=0}^{\infty} (\lambda_{t+\tau}^{\$,*} - \lambda_{t+\tau}^{*,*}) + \mathbb{E}_t \sum_{\tau=0}^{\infty} (y_{t+\tau}^{\$} - y_{t+\tau}^*) - \mathbb{E}_t \sum_{\tau=0}^{\infty} \left(RP_{t+j}^* - \frac{1}{2} Var_{t+j}[\Delta s_{t+j+1}] \right) + \bar{s}. \tag{37}$$

The term $\bar{s} = \mathbb{E}_t[\lim_{j\to\infty} \; s_{t+j}]$ which is constant under the assumption that the nominal exchange rate is stationary.

Last, we construct the basis measure:

$$\begin{aligned} x_t^{Treas} &\equiv y_t^{\$} + (f_t^1 - s_t) - y_t^* \\ &= (y_t^{\$} - y_t^{\$,Libor}) - (y_t^* - y_t^{*,Libor}) \\ &= -(1 - \beta^{\$,*})\lambda_t^{\$,*} + (1 - \beta^{*,*})\lambda_t^{*,*} \end{aligned}$$

The basis reflects the difference between the relative yields of dollar government bonds and LIBOR deposits, and foreign government bonds and foreign deposits.

Proposition 3. *Under the assumption that $\beta^{\$,*} = \beta^{*,*}$, the level of the nominal exchange can be written as:*

$$s_t = -\mathbb{E}_t \sum_{\tau=0}^{\infty} \frac{x_t^{Treas}}{1 - \beta_t^{\$,*}} + \mathbb{E}_t \sum_{\tau=0}^{\infty} (y_{t+\tau}^{\$} - y_{t+\tau}^*) - \mathbb{E}_t \sum_{\tau=0}^{\infty} \left(RP_{t+\tau}^* - \frac{1}{2} Var_{t+\tau}[\Delta s_{t+\tau+1}] \right) + \bar{s}. \tag{38}$$

The assumption that the beta's for U.S. and foreign LIBOR are the same means that the relative safety of these assets are the same regardless of currency. To a first order, the assumption seems plausible to us.

Separate Online Appendix

A Data Sources

We start by discussing the Panel Dataset. For the FX data, 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, BBGBPYF, BBAUDSP, BBAUDYF, BBCADSP, BBCADYF, BBDEMSP, BBDEMYF, BBJPYSP, BBJPYYF, BNZDSP, BBNZDYF, BBNOKSP, BBNOKYF, BBSEKSP, BBSEKYF, BBCHFSP, BBCHFYF, AUSTDOL, UKAUDYF, CNDOLLR, UKCADYF, DMARKER, UKDEMYF, JAPAYEN, UKJPYYF, NZDOLLR, UKNZDYF, NORKRON, UKNOKYF, SWEKRON, UKSEKYF, SWISSFR, UKCHFYF, UKDOLLR, UKUSDYF.*

For the Government Bond Yields (see Table A.2), 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 A.3), 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.

Finally, for the longer US/UK dataset, we rely on Global Financial Data as the main source.

Table A.1: Country Composition of Unbalanced Panel

Country	Maturity	Source	Ranges			
'Australia'	12	All	199912 - 201707			
'Canada'	12	All	199312 - 201707			
'Germany'	12	All	199707 - 201707			
'Japan'	12	All	199504 - 201707			
'New Zealand'	12	All	199603 - 200905	201006 - 201212	201310 - 201412	201606 - 201707
'Norway'	12	All	199001 - 199611	199701 - 201707		
'Sweden'	12	All	199103 - 199611	199701 - 201304	201306 - 201707	
'Switzerland'	12	All	198801 - 201707			
'United Kingdom'	12	All	199707 - 201707			
'United States'	12	All	198801 - 201707			

Table A.2: Sources for Government Bond Yields

Country	Maturity	Months		Mnemonic
'Australia'	12	'Bloomberg'		GTAUD1Y Govt
'Canada'	12	'Bank of Canada (Datastream)'		CNTBB1Y
'Germany'	12	'Bloomberg'		GTDEM1Y Govt
'Japan'	12	'Bloomberg'		GTJPY1Y Govt
'New Zealand'	12	'Bloomberg'	1	GTNZD1Y Govt
'New Zealand'	12	'Reserve Bank of New Zealand (Datastream)'	2	NZGBY1Y
'Norway'	12	'Oslo Bors'		ST3X
'Sweden'	12	'Sveriges Riksbank (from Cristina)'	2	
'Sweden'	12	'Sveriges Riksbank (website)'	1	
'Switzerland'	12	'Swiss National Bank'		
'United Kingdom'	12	'Bloomberg'		GTGBP1Y Govt
'United States'	12	'Bloomberg'	1	GB12 Govt
'United States'	12	'FRED'	2	

The numbers indicate which source takes precedence.

Table A.3: Sources for LIBOR

Country	Maturity	Source	Mnemonic
'Australia'	12	'Bank Bill (Bloomberg)'	ADBB12M Curncy
'Australia'	12	'Bank Bill Swap (Bloomberg)'	BBSW1Y Index/BBSW1MD Index
'Canada'	12	'CDOR (Bloomberg)'	CDOR12 Index
'Australia'	12	'BBA-ICE LIBOR (Datastream)'	BBAUD12
'New Zealand'	12	'Bank Bill (Bloomberg)'	NDBB12M Curncy
'Canada'	12	'BBA-ICE LIBOR (Datastream)'	BBCAD12
'Germany'	12	'BBA-ICE LIBOR (Datastream)'	BBDEM12
'Japan'	12	'BBA-ICE LIBOR (Datastream)'	BBJPY12
'New Zealand'	12	'BBA-ICE LIBOR (Datastream)'	BBNZD12
'Norway'	12	'NIBOR (Bloomberg)'	NIBOR12M Index
'Norway'	12	'Norwegian Krone Deposit (Bloomberg)'	NKDR1 Curncy
'Sweden'	12	'BBA-ICE LIBOR (Datastream)'	BBSEK12
'Sweden'	12	'STIBOR (Bloomberg)'	STIB1Y Index
'Sweden'	12	'Swedish Krona Deposit (Bloomberg)'	SKDR1 Curncy
'Switzerland'	12	'BBA-ICE LIBOR (Datastream)'	BBCHF12
'United Kingdom'	12	'BBA-ICE LIBOR (Datastream)'	BBGBP12
'United States'	12	'BBA-ICE LIBOR (Datastream)'	BBUSD12

Table A.4: Sources for US-UK Time Series

	Source	Mnemonic	Range
Spot FX	GFD	$GBPUSD$	1960 – 2017
3M Forward	GFD	$GBPUSD3D$	1960 – 2017
12M Forward	GFD	$GBPUSD12D$	1960 – 2017
3M T-bill UK	GFD	$ITGBR3D$	1960 – 2017
1Y Note UK	GFD	$IGGBR1D$	1979 – 2017
1Y Note US	FRED	$DTB1YR$	1960 – 2017
1Y Zero-Coupon	BoE		1970 – 1979

(GFD is Global Financial Data. FRED is the Federal Reserve Economic Database at the Federal Reserve Bank of St Louis. BoE is the Bank of England.)

B Campbell-Shiller Decomposition

Define $\boldsymbol{z}_t' = \begin{bmatrix} x_t & i_t & s_t \end{bmatrix}$, the vector of US Treasury basis, the nominal interest rate differential between US and the foreign country, and the nominal dollar exchange rate. We estimate following the first-order VAR for $\boldsymbol{z}_t$:

$$\boldsymbol{z}_t = \boldsymbol{\Gamma}_0 + \boldsymbol{\Gamma}_1 \boldsymbol{z}_{t-1} + \boldsymbol{a}_t,$$

where $\boldsymbol{\Gamma}_0$ is a 3-dimensional vector, $\boldsymbol{\Gamma}_1$ is a 3×3 matrix and $\boldsymbol{a}_t$ is a sequence of white noise random vector with mean zero and variance covariance matrix Σ. The variance covariance matrix is required to be positive definite.

The log of the currency excess return is given by $rx_t = s_t - s_{t-1} + d_{t-1}$, where d_{t-1} is the nominal interest rate differential between US and the foreign country. By Proposition 1.3, the realized risk premium component of the log currency excess return is the realized log excess return minus the convenience yield: $rp_t = rx_t - \frac{1}{1-\beta^*} \times x_{t-1}$. 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:

$$\begin{bmatrix} rp_t \\ x_t \\ i_t \\ q_t \end{bmatrix} = \begin{bmatrix} \gamma_0 \\ \Gamma_{0,1} \\ \Gamma_{0,2} \\ \Gamma_{0,3} \end{bmatrix} + \begin{bmatrix} 0 & \Gamma_{3,1} - \frac{1}{1-\beta^*} & \Gamma_{3,2} + 1 & \Gamma_{3,3} - 1 \\ 0 & \Gamma_{1,1} & \Gamma_{1,2} & \Gamma_{1,3} \\ 0 & \Gamma_{2,1} & \Gamma_{2,2} & \Gamma_{2,3} \\ 0 & \Gamma_{3,1} & \Gamma_{3,2} & \Gamma_{3,3} \end{bmatrix} \begin{bmatrix} rp_{t-1} \\ x_{t-1} \\ i_{t-1} \\ q_{t-1} \end{bmatrix} + \begin{bmatrix} a_{3,t} \\ a_{1,t} \\ a_{2,t} \\ a_{3,t} \end{bmatrix} \tag{39}$$

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

Accordingly, we can define the state as the vector of demeaned variables: $\boldsymbol{y}_t' = \begin{bmatrix} \tilde{rp}_t & \tilde{x}_t & \tilde{i}_t & \tilde{q}_t \end{bmatrix}$. $\boldsymbol{y}_t$ is a VAR process of order 1

$$\boldsymbol{y}_t = \boldsymbol{\Psi}_1 \boldsymbol{y}_{t-1} + \boldsymbol{u}_t,$$

where $\boldsymbol{\Psi}_1$ is the 4×4 matrix defined in (39) and $\boldsymbol{u}_t$ is the 4×1 vector of residuals defined above.

B.1 Identification of β^*

The Treasury basis shock affects future Treasury basis, future interest rates, and future risk premia. Suppose that the response of the risk premium component to on orthogonal basis shock is governed by κ:

$$\Delta \mathbb{E}_t \sum_{\tau=0}^{\infty} RP_{t+\tau}^* = \kappa \Delta x_t. \tag{40}$$

Then we can identify β^* from the response of the exchange rate to an orthogonal basis shock:

$$\frac{1}{1-\beta^*} = -\frac{\Delta q_t - \Delta \mathbb{E}_t \sum_{\tau=0}^{\infty} (r_{t+\tau}^{\$} - r_{t+\tau}^*) + \kappa \Delta x_t}{\Delta \mathbb{E}_t \sum_{\tau=0}^{\infty} x_{t+\tau}}. \tag{41}$$

β^* depends on κ, the response of the risk premium component to a Treasury basis shock. Our identification assumption is that $\kappa = 0$; in other words, we assume that the risk premium component is not affected by a Treasury basis shock. Note that this does not rule out a non-zero unconditional covariance between CY news and DR news as driven by Treasury basis shocks, because other shocks also affect CY and DR, and induce a positive covariance between CY and DR. To see the algebra, start from

$$\begin{aligned} N_{DR,t} &= (\mathbb{E}_t - \mathbb{E}_{t-1}) \left[\sum_{j=1}^{\infty} rp_{t+j} \right] = \boldsymbol{e}_1' \boldsymbol{\Psi}_1 (I - \boldsymbol{\Psi}_1)^{-1} \boldsymbol{u}_t, \\ N_{CF,t} &= (\mathbb{E}_t - \mathbb{E}_{t-1}) \left[\sum_{j=0}^{\infty} i_{t+j} \right] = \boldsymbol{e}_3' (I - \boldsymbol{\Psi}_1)^{-1} \boldsymbol{u}_t, \\ N_{CY,t} &= -(\mathbb{E}_t - \mathbb{E}_{t-1}) \left[\sum_{j=0}^{\infty} \frac{1}{1-\beta^*} x_{t+j} \right] = -\frac{1}{1-\beta^*} \boldsymbol{e}_2' (I - \boldsymbol{\Psi}_1)^{-1} \boldsymbol{u}_t \end{aligned}$$

where

$$\boldsymbol{\Psi}_1 = \begin{bmatrix} 0 & \Gamma_{3,1} - \frac{1}{1-\beta^*} & \Gamma_{3,2}+1 & \Gamma_{3,3}-1 \\ 0 & \Gamma_{1,1} & \Gamma_{1,2} & \Gamma_{1,3} \\ 0 & \Gamma_{2,1} & \Gamma_{2,2} & \Gamma_{2,3} \\ 0 & \Gamma_{3,1} & \Gamma_{3,2} & \Gamma_{3,3} \end{bmatrix} \tag{42}$$

is a function of β^*.

These components satisfy the following identity:

$$N_{CY,t} = -N_{CF,t} + N_{DR,t} + \boldsymbol{e}_1' \boldsymbol{u}_t$$

i.e.

$$-\frac{1}{1-\beta^*} \boldsymbol{e}_2' (I - \boldsymbol{\Psi}_1)^{-1} \boldsymbol{u}_t = -\boldsymbol{e}_3' (I - \boldsymbol{\Psi}_1)^{-1} \boldsymbol{u}_t + \boldsymbol{e}_1' \boldsymbol{\Psi}_1 (I - \boldsymbol{\Psi}_1)^{-1} \boldsymbol{u}_t + \boldsymbol{e}_1' \boldsymbol{u}_t \tag{43}$$

By the Cholesky Decomposition:

$$var(\boldsymbol{u}_t) \equiv \Omega = AA'.$$

Define $\tilde{\boldsymbol{u}}_{\boldsymbol{t}} = A^{-1} \boldsymbol{u}_t$, then $var(\tilde{\boldsymbol{u}}_{\boldsymbol{t}}) = I$. Since only the second element of $\tilde{\boldsymbol{u}}_{\boldsymbol{t}}$ contains basis shock (recall $\boldsymbol{u}_{\boldsymbol{t}}$ is augmented by rp_t), we can express (7) as

$$-\frac{1}{1-\beta^*} \boldsymbol{e}_2' (I - \boldsymbol{\Psi}_1)^{-1} A \boldsymbol{e}_2' \tilde{\boldsymbol{u}}_{\boldsymbol{t}} = -\boldsymbol{e}_3' (I - \boldsymbol{\Psi}_1)^{-1} A \boldsymbol{e}_2' \tilde{\boldsymbol{u}}_{\boldsymbol{t}} + \boldsymbol{e}_1' \boldsymbol{\Psi}_1 (I - \boldsymbol{\Psi}_1)^{-1} A \boldsymbol{e}_2' \tilde{\boldsymbol{u}}_{\boldsymbol{t}} + \boldsymbol{e}_1' A \boldsymbol{e}_2' \tilde{\boldsymbol{u}}_{\boldsymbol{t}} \tag{44}$$

This is exactly the same as (4), rearranged as below:

$$-\frac{1}{1-\beta^*} \mathbb{E}_t \sum_{\tau=0}^{\infty} dx_{t+\tau} = -\mathbb{E}_t \sum_{\tau=0}^{\infty} (dr_{t+\tau}^{\$} - dr_{t+\tau}^*) + \kappa dx_t + dq_t \tag{45}$$

In other words, we pick $\kappa = 0$ so that $\Delta DR = \kappa \Delta x_t = 0$ following a basis shock $A\boldsymbol{e}_2'\tilde{\boldsymbol{u}}_{\boldsymbol{t}}$. However, the Cholesky decomposition also allows for an interest rate shock and an exchange rate shock. By definition, these shocks do not affect today's Treasury basis, but they may affect future Treasury bases and therefore the CY component. For example, consider an interest rate shock $A\boldsymbol{e}_3'\tilde{\boldsymbol{u}}_{\boldsymbol{t}}$. The impulse responses satisfy

$$-\frac{1}{1-\beta^*}\boldsymbol{e}_2'(I-\boldsymbol{\Psi}_1)^{-1}A\boldsymbol{e}_3'\tilde{\boldsymbol{u}}_{\boldsymbol{t}} \quad = \quad -\boldsymbol{e}_3'(I-\boldsymbol{\Psi}_1)^{-1}A\boldsymbol{e}_3'\tilde{\boldsymbol{u}}_{\boldsymbol{t}} + \boldsymbol{e}_1'\boldsymbol{\Psi}_1(I-\boldsymbol{\Psi}_1)^{-1}A\boldsymbol{e}_3'\tilde{\boldsymbol{u}}_{\boldsymbol{t}} + \boldsymbol{e}_1'A\boldsymbol{e}_3'\tilde{\boldsymbol{u}}_{\boldsymbol{t}} \tag{46}$$

Following this shock, the CY news $\boldsymbol{e}_3'(I-\boldsymbol{\Psi}_1)^{-1}A\boldsymbol{e}_3'\tilde{\boldsymbol{u}}_{\boldsymbol{t}}$ and the DR news $\boldsymbol{e}_1'\boldsymbol{\Psi}_1(I-\boldsymbol{\Psi}_1)^{-1}A\boldsymbol{e}_3'\tilde{\boldsymbol{u}}_{\boldsymbol{t}}$ can be nonzero. So $cov(CY, DR)$ can be nonzero.

C Impulse Responses

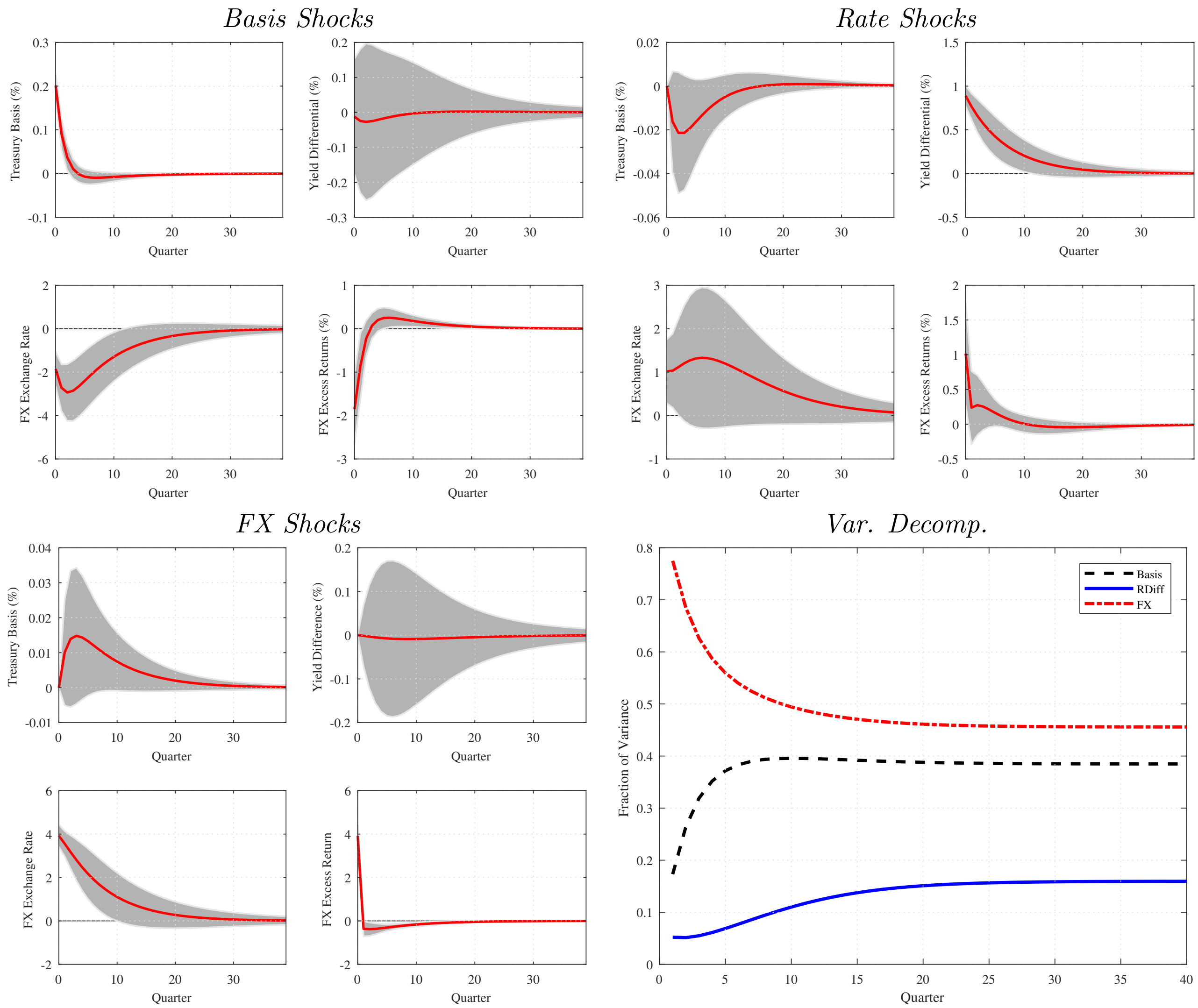

Figure A.1: Panel Impulse Responses.

The red line plots the impulse response of an orthogonalized one-standard-deviation shock on the basis (top left panel), the real interest rate differential (top right panel), the log real spot exchange rate (bottom left panel), and the quarterly log excess return on a long position in dollars (bottom 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. The ordering is $\left[\overline{x}_t, r_t^{\$} - \overline{r}_t^*, q_t\right]$.

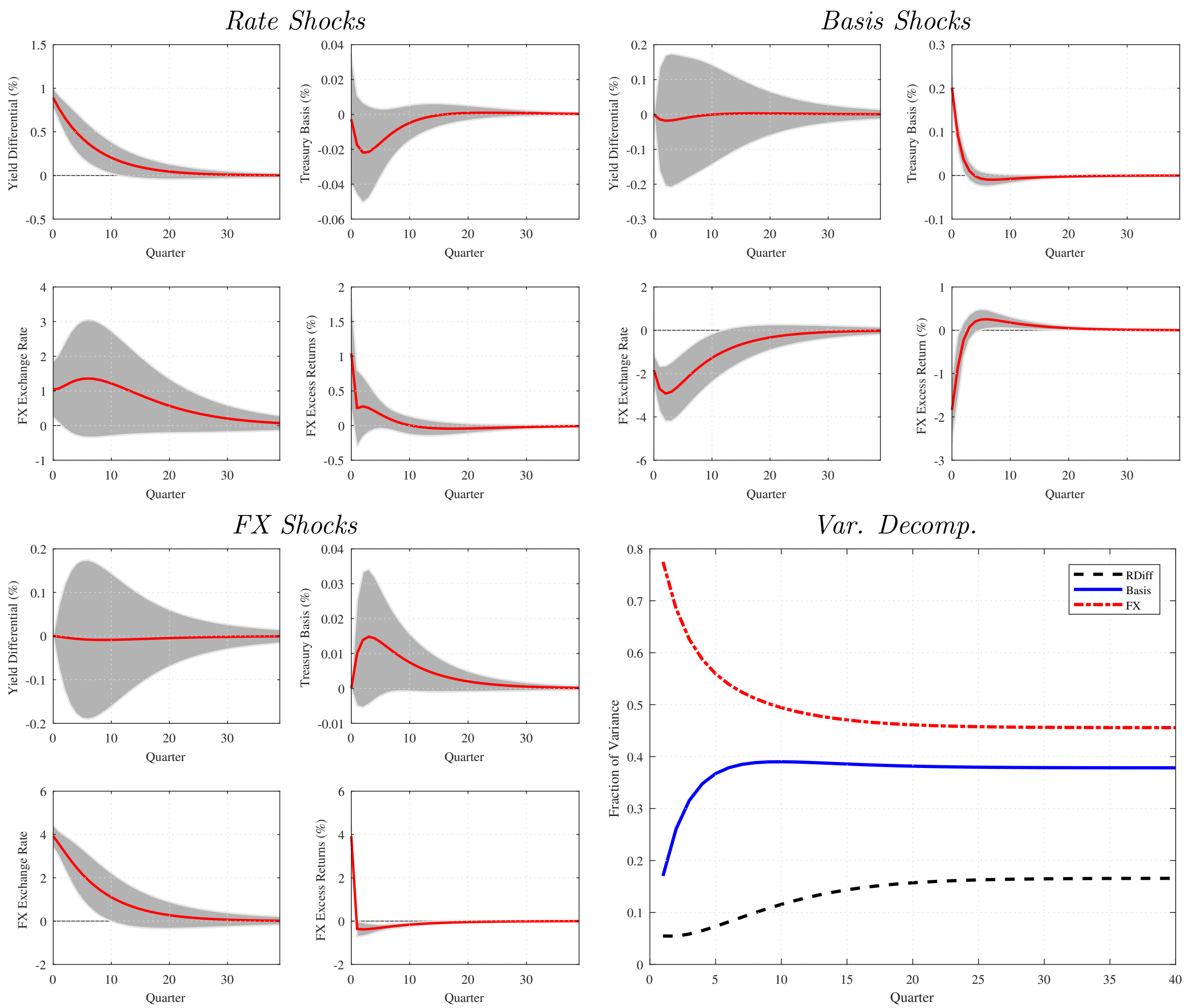

Figure A.2: Panel Impulse Responses: Alternate Ordering.

The red line plots the impulse response of an orthogonalized one-standard-deviation shock on the real interest rate differential (top left panel), the the basis (top right panel), the log real spot exchange rate (bottom left panel), and the quarterly log excess return on a long position in dollars (bottom 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. The ordering is $\left[r_t^{\$} - \overline{r}_t^*, \overline{x}_t, q_t\right]$.

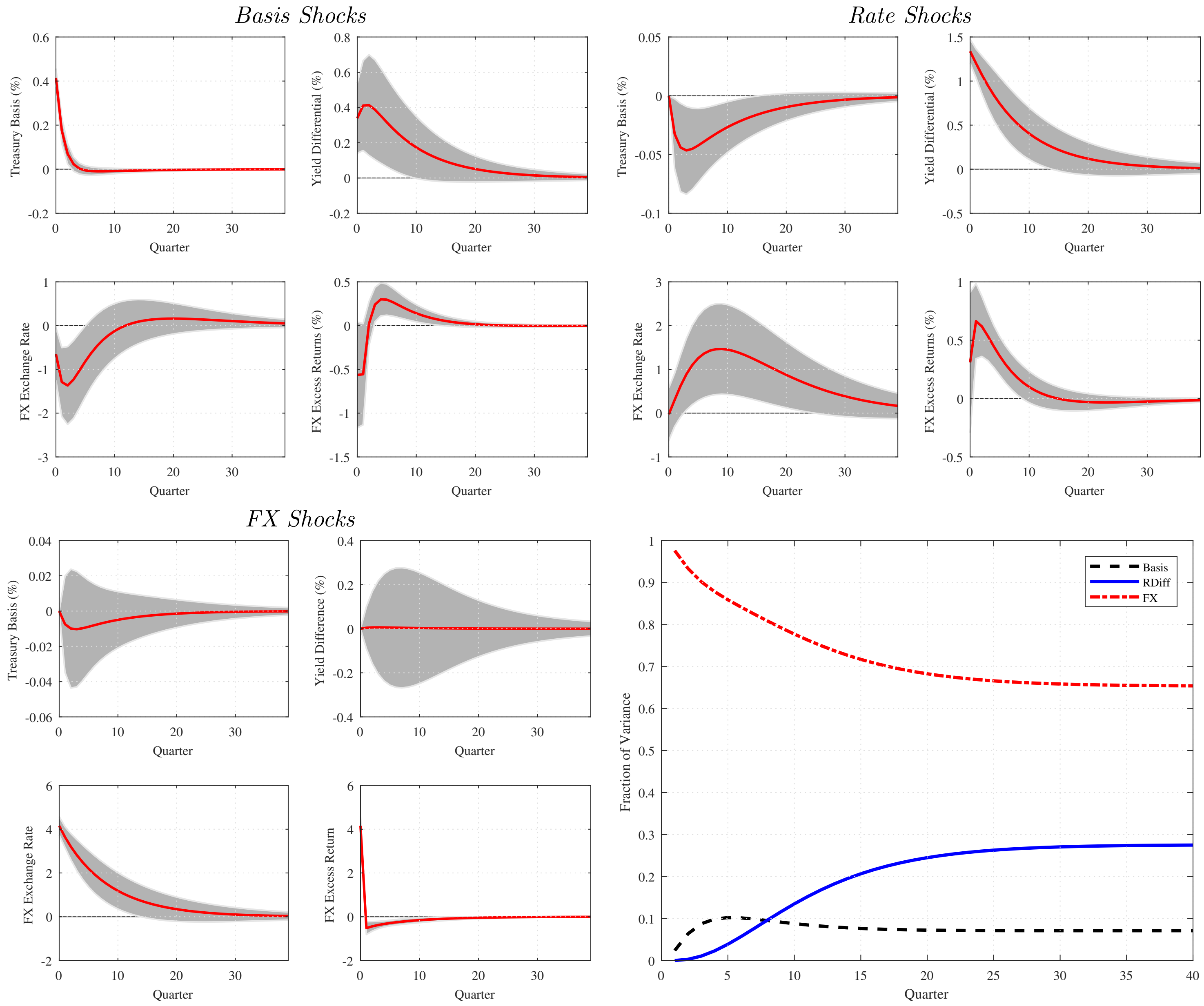

Figure A.3: UK/US Impulse Responses.

The red line plots the impulse response of of a one-standard-deviation orthogonalized shock to the US/UK Treasury basis on the basis (top left panel), the real US/UK interest rate differential (top right panel), and the log real GBP-per-USD spot exchange rate (bottom left panel), as well as the quarterly excess return (bottom 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 1970Q1 to 2016Q2. The ordering is $\left[\overline{x}_t, r_t^{\$} - \overline{r}_t^*, q_t\right]$.

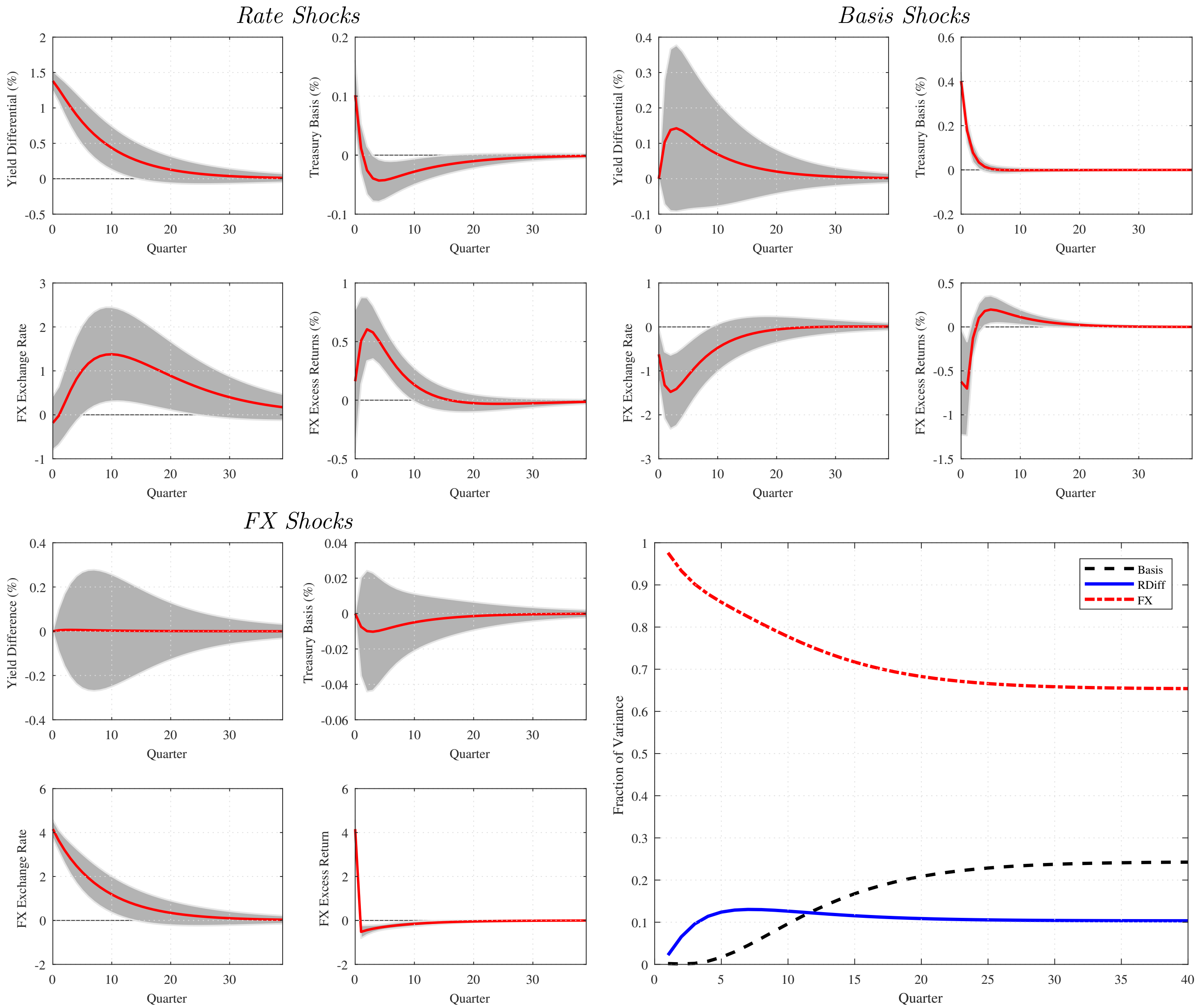

Figure A.4: UK/US Impulse Responses: Alternate Ordering.

The red line plots the impulse response of of a one-standard-deviation orthogonalized shock to the US/UK Treasury basis on the basis (top left panel), the real US/UK interest rate differential (top right panel), and the log real GBP-per-USD spot exchange rate (bottom left panel), as well as the quarterly excess return (bottom 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 1970Q1 to 2016Q2. The ordering is $\left[\overline{x}_t, r_t^{\$} - \overline{r}_t^*, q_t\right]$.

D Robustness

D.1 Explaining Variation in the Dollar Using Change in Treasury Basis

In Table 3 and 4, we use innovation in Treasury basis as the explanatory variable. Here we use the change $\Delta \bar{x}_t^{Treas} = \bar{x}_t^{Treas} - \bar{x}_{t-1}^{Treas}$ instead.

Table A.5: Average Treasury Basis and the USD Spot Nominal 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 change in the average Treasury basis, $\Delta \overline{x}^{Treas}$, as log yield (i.e. 50 basis points is 0.005), the lagged value of the change, the change in the LIBOR basis, and the change in the US-to-foreign Treasury yield differential. Data is quarterly. OLS standard errors in parentheses.

	1988Q1−2017Q2					1988Q1−2007Q4		2008Q1−2017Q2	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
$\Delta \overline{x}^{Treas}$	-3.93		-5.93		-5.79	-2.19		-9.27	
	(1.87)		(1.87)		(1.63)	(2.31)		(3.03)	
$\Delta \bar{x}^{LIBOR}$		3.32					8.09		-5.97
		(2.51)					(3.17)		(3.67)
Lag $\Delta \overline{x}^{Treas}$			-6.01		-4.65				
			(1.87)		(1.65)				
$\Delta(y^{\$} - \bar{y}^*)$				3.84	3.71				
				(0.66)	(0.62)				
R^2	3.7	1.5	12.0	22.6	33.4	1.1	7.7	21.1	7.0
N	117	117	116	117	116	80	80	37	37

Table A.6: US/UK Treasury Basis and the Spot Real Exchange Rate

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

	1970Q1 - 2016Q2			1980Q1 - 2016Q2	1990Q1 - 2016Q2
	(1)	(2)	(3)	(4)	(5)
$\Delta\overline{x}^{Treas}$	-1.23		-1.26	-3.05	-11.70
	(0.71)		(0.71)	(1.49)	(2.22)
Lag $\Delta\overline{x}^{Treas}$	-1.85		-1.67	-5.74	-11.69
	(0.71)		(0.71)	(1.45)	(2.22)
$\Delta(y^{\$} - \bar{y}^{UK})$		0.13	0.11		
		(0.06)	(0.06)		
R^2	4.0	2.4	5.8	10.3	33.2
N	183	190	183	144	104

D.2 Explaining Variation in the Dollar Using 3M Treasury Basis

This section reports the regression results obtained when we use the 3-month Treasury basis instead of the 12-month Treasury basis, and use the 3-month interest rates instead of the 12-month interest rates.

Table A.7: Average 3M-Treasury Basis and the USD Spot Nominal 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, $\Delta\overline{x}^{Treas}$, as log yield (i.e. 50 basis points is 0.005), the lagged value of the innovation, the innovation in the LIBOR basis, and the innovation in the US-to-foreign Treasury yield differential. Data is quarterly. OLS standard errors in parentheses.

	1988Q1−2017Q2					1988Q1−2007Q4		2008Q1−2017Q2	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Last observation in 3 months									
$\Delta\overline{x}^{Treas}$	0.67		0.47		0.02	4.85		-1.79	
	(1.09)		(1.10)		(1.09)	(1.72)		(1.37)	
$\Delta\bar{x}^{LIBOR}$		-1.73					1.31		-3.21
		(1.72)					(2.76)		(2.36)
Lag $\Delta\overline{x}^{Treas}$			-1.24		-1.22				
			(1.10)		(1.08)				
$\Delta(y^{\$} - \bar{y}^{*})$				1.53	1.51				
				(0.59)	(0.60)				
Constant	0.0002	0.0002	0.0002	0.0002	0.0003	-0.002	-0.003	0.01	0.003
	(0.004)	(0.004)	(0.004)	(0.004)	(0.004)	(0.004)	(0.004)	(0.01)	(0.01)
R^2	0.3	0.8	1.3	5.2	6.3	8.5	0.3	4.6	5.0
N	125	125	124	125	124	88	88	37	37
Average across 3 months									
$\Delta\overline{x}^{Treas}$	-1.61		-1.76		-1.98	1.91		-8.92	
	(1.46)		(1.48)		(1.46)	(1.67)		(2.45)	
$\Delta\bar{x}^{LIBOR}$		-9.37					0.16		-16.44
		(3.57)					(5.26)		(5.27)
Lag $\Delta\overline{x}^{Treas}$			-2.58		-2.26				
			(1.46)		(1.44)				
$\Delta(y^{\$} - \bar{y}^{*})$				1.47	1.77				
				(0.70)	(0.72)				
Constant	-0.001	-0.001	-0.0004	-0.001	-0.0002	-0.003	-0.003	0.01	-0.0001
	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)	(0.004)	(0.004)	(0.01)	(0.01)
R^2	1.0	5.3	3.2	3.5	7.8	1.5	0.0	27.4	21.7
N	125	125	124	125	124	88	88	37	37

Table A.8: US/UK 3M-Treasury Basis and the Spot Real Exchange Rate

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

	1970Q1 - 2016Q2			1980Q1 - 2016Q2	1990Q1 - 2016Q2
	Average across 3 months				
$\Delta\overline{x}^{Treas}$	-0.92		-0.82	-0.08	-1.99
	(0.48)		(0.48)	(1.02)	(1.23)
Lag $\Delta\overline{x}^{Treas}$	-0.53		-0.52	-3.75	-5.61
	(0.48)		(0.48)	(0.99)	(1.23)
$\Delta(y^{\$} - \overline{y}^{UK})$		0.16	0.14		
		(0.08)	(0.08)		
R^2	2.8	2.1	4.4	9.7	17.3
N	183	185	183	144	104

D.3 Explaining Variation in the Dollar in Subsamples

This section repeats the regressions in Table 3 in subsamples. We split the sample into calm periods and volatile periods. The calm periods are the dates in which the average US Treasury basis is above or equal to the 25th percentile, and the volatile periods are the dates in which the average US Treasury basis is below the 25th percentile.

The 25th percentile of the distribution of the average US Treasury basis is -68 basis points. We find that the US dollar's exchange rate does comove with the average US Treasury basis in calm periods.

Table A.9: Average Treasury Basis and the USD Spot Nominal Exchange Rate, Calm Periods

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, $\Delta\overline{x}^{Treas}$, as log yield (i.e. 50 basis points is 0.005), the lagged value of the innovation, the innovation in the LIBOR basis, and the innovation in the US-to-foreign Treasury yield differential. Data is quarterly. OLS standard errors in parentheses.

	1988Q1−2017Q2					1988Q1−2007Q4		2008Q1−2017Q2	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
$\Delta\overline{x}^{Treas}$	-16.77		-17.43		-10.89	-14.38		-24.82	
	(3.06)		(3.22)		(3.36)	(3.56)		(6.21)	
$\Delta\bar{x}^{LIBOR}$		-11.11					-14.48		-7.73
		(4.06)					(6.37)		(5.82)
Lag $\Delta\overline{x}^{Treas}$			-2.06		-0.52				
			(2.93)		(2.72)				
$\Delta(y^{\$} - \bar{y}^{*})$				4.90	3.56				
				(0.80)	(0.87)				
Constant	0.002	-0.01	0.004	-0.01	-0.001	-0.002	-0.01	0.01	-0.004
	(0.004)	(0.004)	(0.005)	(0.004)	(0.004)	(0.01)	(0.01)	(0.01)	(0.01)
R^2	25.8	8.0	26.3	30.3	38.6	23.5	8.9	34.0	5.4
N	88	88	88	88	88	55	55	33	33

Table A.10: Average Treasury Basis and the USD Spot Nominal Exchange Rate, Volatile Periods

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, $\Delta\overline{x}^{Treas}$, as log yield (i.e. 50 basis points is 0.005), the lagged value of the innovation, the innovation in the LIBOR basis, and the innovation in the US-to-foreign Treasury yield differential. Data is quarterly. OLS standard errors in parentheses.

	1988Q1−2017Q2					1988Q1−2007Q4		2008Q1−2017Q2	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
$\Delta\overline{x}^{Treas}$	-1.09		-4.79		-6.72	1.05		-5.41	
	(4.14)		(4.09)		(3.62)	(5.22)		(4.83)	
$\Delta\bar{x}^{LIBOR}$		6.83					14.86		-7.40
		(4.72)					(5.62)		(4.42)
Lag $\Delta\overline{x}^{Treas}$			-8.98		-8.52				
			(3.80)		(3.32)				
$\Delta(y^{\$} - \bar{y}^{*})$				3.11	3.19				
				(1.17)	(1.07)				
Constant	0.03	0.04	0.01	0.03	0.01	0.03	0.03	0.04	0.04
	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.02)	(0.01)	(0.02)	(0.01)
R^2	0.3	7.2	18.5	20.7	40.5	0.2	24.1	29.5	48.3
N	29	29	28	29	28	24	24	5	5

D.4 Using Other Countries as the Base Country

In Table 3, we fix the US as the base country and take an equally weighted cross-sectional average of exchange rates and Treasury basis of other countries against the US. In the following table, we use a different base country, and calculate the equally weighted cross-sectional average of exchange rates and Treasury basis of other non-US countries against this base country. We report the coefficient of the regression of nominal exchange rate movement on Treasury basis innovation.

Table A.11: Explain exchange rate movement using Treasury basis innovation.

We regress the exchange rate movement on concurrent Treasury basis innovation. A higher exchange rate means a stronger base currency. For each non-US country, we exclude the US when we calculate its average Treasury basis and average exchange rate movement against other non-US countries.

	Dependent variable:									
	Base Country's Exchange Rate Movement									
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
	US	AUS	CAN	DEU	JPN	NZL	NOR	SWE	SWI	UK
innov	−9.62	−0.38	2.49	−5.88	3.19	−3.94	0.01	−0.97	1.76	2.64
	(2.05)	(3.38)	(1.61)	(3.87)	(4.83)	(1.80)	(0.95)	(0.85)	(1.48)	(2.32)
Constant	0.002	0.001	0.0002	0.0000	−0.002	0.0001	−0.001	−0.003	0.01	−0.004
	(0.004)	(0.005)	(0.004)	(0.003)	(0.01)	(0.01)	(0.003)	(0.003)	(0.003)	(0.004)
Observations	117	69	93	78	87	69	108	104	108	78
R^2	0.16	0.0002	0.03	0.03	0.01	0.07	0.0000	0.01	0.01	0.02

D.5 Market Microstructure

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. By computing a quarterly average, we average out bid-ask bounce and thus likely measure true mid-market prices. The relation we uncover is quite strong in this averaged data (in fact it is stronger than the end-of-quarter data of Table 3).[28] 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 1.94% move in the exchange rate, which is also an order of magnitude larger than bid-ask spreads. Finally, the evidence in column (3) of Table 3 for momentum relates the lagged innovation in the basis to next quarter's change in the exchange rate.[29]

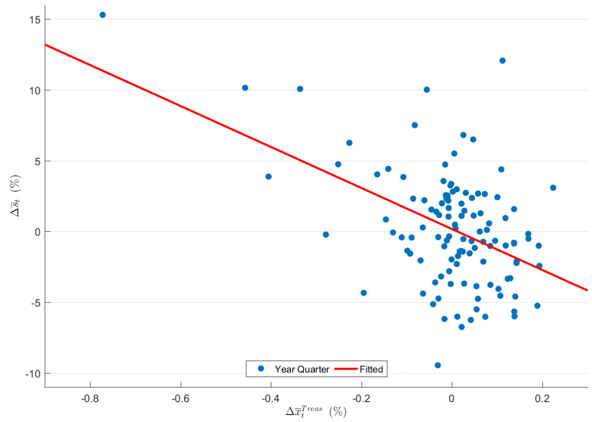

Figure A.5: Scatter plot of changes in the log exchange rate, averaged over a quarter, against shocks to the quarterly average basis. Data is from 1988Q1 to 2017Q2. In red we plot the fitted regression line. The R^2 is 22.8% and the slope coefficient is -14.6 with a t-statistic of 5.8.

[28] Figure A.5 presents a scatter plot of the change in the quarterly average log exchange rate against the change in the quarterly average basis.

[29] In section D.7 of the separate Appendix, we also show predictability evidence in Table A.14 and A.16 relating the current basis to future changes in the exchange rate. Our results are evidently not driven by micro-structure effects.

D.6 Forecasting Returns and Exchange Rates Using 3-month Treasury Basis

This section reports predictability results obtained using the 3-month Treasury basis instead of the 12-month Treasury basis. Because the time series of the 3-month Treasury basis is volatile, we use the quarterly average instead of the last observation in each quarter.

Table A.12: Predicting Currency Excess Returns in the Panel using 3M Basis

The dependent variable is either $rx^{fx}_{t\to t+k}$ or $(4/k)\Delta s_{t\to t+k}$. The independent variables are the average Treasury basis, $\overline{x}^{Treas}$, 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 nominal Libor rate difference $(y_t^{\$,Libor} - \overline{y}_t^{*,Libor})$ in units of log yield. Data is quarterly from 1988Q1 to 2017Q2. Heteroskedasticity and autocorrelation adjusted standard errors in parentheses.

Panel A: Dependent Variable is Excess Return				
Last observation in 3 months				
	3-month	1-year	2-year	3-year
$\overline{x}^{Treas}$	-4.61	3.47	4.31	5.95
	(4.14)	(5.44)	(3.59)	(2.87)
$y_t^{\$,Libor} - \overline{y}_t^{*,Libor}$	0.91	1.06	0.80	0.53
	(1.06)	(0.86)	(0.55)	(0.39)
$\Delta\overline{x}^{Treas}$		-3.80	-3.56	-4.69
		(3.88)	(2.21)	(1.84)
Constant	-0.02	0.01	0.01	0.02
	(0.02)	(0.03)	(0.03)	(0.02)
R^2	2.78	8.51	11.03	13.07
N	125	121	117	113
Average across 3 months				
	3-month	1-year	2-year	3-year
$\overline{x}^{Treas}$	-2.66	2.46	4.62	5.77
	(5.49)	(5.02)	(3.76)	(2.72)
$y_t^{\$,Libor} - \overline{y}_t^{*,Libor}$	1.35	1.27	1.00	0.71
	(0.81)	(0.78)	(0.53)	(0.39)
$\Delta\overline{x}^{Treas}$		-3.34	-5.44	-5.00
		(4.06)	(2.52)	(1.60)
Constant	-0.01	0.01	0.01	0.01
	(0.02)	(0.03)	(0.02)	(0.02)
R^2	4.49	11.17	16.54	18.69
N	125	121	117	113

Table A.13: Predicting Currency Excess Returns in the US/UK Data using 3M Basis

The dependent variable is either $rx^{fx}_{t\to t+k}$ or $(4/k)\Delta s_{t\to t+k}$. 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 nominal Treasury yield difference $(y^{\$} - y^{*})$ in units of log yield. Data is quarterly from 1970Q1 to 2016Q2. Heteroskedasticity and autocorrelation adjusted standard errors in parentheses.

Panel A: Dependent Variable is Excess Return				
Average across 3 months: Full Sample				
	3-month	1-year	2-year	3-year
$\overline{x}^{Treas}$	-3.07	-1.04	-0.43	0.32
	(1.32)	(1.19)	(1.06)	(0.82)
$y^{\$} - \overline{y}^{*}$	2.88	1.67	1.21	0.99
	(1.17)	(0.86)	(0.58)	(0.46)
Lag $\Delta\overline{x}^{Treas}$		-1.23	-1.49	-1.63
		(0.80)	(0.67)	(0.45)
Constant	0.03	0.02	0.02	0.01
	(0.02)	(0.02)	(0.02)	(0.02)
R^2	10.1	8.9	8.8	9.7
N	185	184	184	180
Average across 3 months: From 1980				
	3-month	1-year	2-year	3-year
$\overline{x}^{Treas}$	-10.28	1.19	-0.35	4.26
	(5.32)	(5.59)	(5.39)	(3.85)
$y^{\$} - \overline{y}^{*}$	2.30	1.95	1.30	1.33
	(1.57)	(0.95)	(0.74)	(0.57)
Lag $\Delta\overline{x}^{Treas}$		-4.62	-2.72	-5.67
		(4.16)	(4.20)	(2.58)
Constant	0.03	0.03	0.02	0.02
	(0.03)	(0.02)	(0.02)	(0.02)
R^2	15.5	11.6	11.9	11.9
N	145	144	144	140

D.7 Forecasting Exchange Rate Changes using 12M Treasury Basis

This section checks the predictability of nominal exchange rate movements instead of the predictability of currency excess returns.

Table A.14: Forecasting Exchange Rate Changes in Panel

The dependent variable is the annualized change in the exchange rate (in logs) $(4/k)\Delta s_{t \to t+k}$ on a long position in the dollar over k quarters. The independent variables are the average Treasury basis, $\overline{x}^{Treas}$, the nominal Treasury yield difference $(y^{\$} - y^{*})$, the change in the average Treasury basis $\Delta \overline{x}_t^{Treas}$, and the lagged change in the average Treasury basis $\Delta \overline{x}_{t-1}^{Treas}$. Data is quarterly from 1988Q1 to 2017Q2. Heteroskedasticity and autocorrelation adjusted standard errors in parentheses.

	$\overline{x}^{Treas}$	$y^{\$} - \overline{y}^{*}$	$\Delta \overline{x}^{Treas}$	Lag $\Delta \overline{x}^{Treas}$	R^2
			Panel A: 1988-2017		
3 months	-16.76	-1.17	-7.96	2.80	0.08
	(13.15)	(1.36)	(10.29)	(10.25)	
1 year	-0.65	-0.57	-7.02	-2.60	0.05
	(8.46)	(0.92)	(5.51)	(3.89)	
2 years	4.13	-0.28	-6.64	-4.48	0.06
	(4.81)	(0.56)	(3.25)	(2.41)	
3 years	6.94	0.05	-7.09	-4.21	0.10
	(3.64)	(0.34)	(2.54)	(1.91)	
			Panel B: 1988-2007		
3 months	-30.66	-1.37	5.79	14.55	0.13
	(15.04)	(1.47)	(9.51)	(10.52)	
1 year	-10.39	-0.71	-5.02	-3.32	0.14
	(9.22)	(0.88)	(6.83)	(5.13)	
2 years	-3.02	-0.47	-3.22	-3.44	0.07
	(5.09)	(0.56)	(4.00)	(2.92)	
3 years	3.77	-0.03	-6.39	-4.23	0.07
	(4.44)	(0.32)	(3.30)	(2.35)	
			Panel C: 2007-2017		
3 months	17.94	-4.58	-32.05	-29.41	0.22
	(10.92)	(3.04)	(11.78)	(10.40)	
1 year	18.94	-3.06	-6.31	-3.31	0.25
	(6.90)	(2.50)	(5.97)	(3.08)	
2 years	20.55	-0.07	-12.95	-8.59	0.50
	(3.13)	(0.74)	(1.91)	(1.96)	
3 years	13.35	-0.19	-7.26	-5.26	0.35
	(2.80)	(0.70)	(1.79)	(1.39)	

Table A.15: Forecasting 3-year Exchange Rate Changes in Panel

In Panel A (B), the dependent variable is the annualized nominal excess return (in logs) $(4/12)\Delta s_{t\to t+12}$ ($(4/8)\Delta s^{fx}_{t+4\to t+12}$) on a long position in U.S. Treasuries and a short position (equal-weighted) in all foreign bonds over k quarters. The independent variables are the Treasury basis, x^{Treas}, the nominal Treasury yield difference $(y^{\$} - y^{*})$, the change in the Treasury basis $\Delta\overline{x}^{Treas}_t$, and the lagged change in the Treasury basis $\Delta\overline{x}^{Treas}_{t-1}$. Data is quarterly from 1988Q1 to 2017Q2. Heteroskedasticity and autocorrelation adjusted standard errors in parentheses.

	$\overline{x}^{Treas}$	$y^{\$} - \overline{y}^{*}$	$\Delta\overline{x}^{Treas}$	Lag $\Delta\overline{x}^{Treas}$	R^2	$\overline{x}^{Treas}$	$y^{\$} - \overline{y}^{*}$	$\Delta\overline{x}^{Treas}$	Lag $\Delta\overline{x}^{Treas}$	R^2
	Panel A: Change from year t to $t+3$					*Panel B: Change from year $t+1$ to $t+3$*				
1988-2017	2.17				0.01	6.31				0.07
	(2.33)					(2.74)				
	1.98	-0.09			0.01	6.52	0.10			0.07
	(2.24)	(0.29)				(2.59)	(0.34)			
	4.64	-0.01	-4.58		0.06	8.72	0.25	-4.59		0.09
	(2.96)	(0.31)	(1.70)			(3.48)	(0.34)	(2.36)		
	6.94	0.05	-7.09	-4.21	0.10	11.24	0.38	-7.58	-5.37	0.12
	(3.64)	(0.34)	(2.54)	(1.91)		(4.40)	(0.34)	(3.66)	(2.85)	
1988-2007	-0.36				0.00	6.44				0.07
	(2.84)					(3.13)				
	-0.75	-0.14			0.00	6.68	0.09			0.07
	(2.64)	(0.28)				(3.06)	(0.34)			
	1.51	-0.09	-3.55		0.03	8.73	0.22	-4.12		0.08
	(3.65)	(0.29)	(2.07)			(4.23)	(0.36)	(2.95)		
	3.77	-0.03	-6.39	-4.23	0.07	10.86	0.32	-7.07	-4.68	0.10
	(4.44)	(0.32)	(3.30)	(2.35)		(5.42)	(0.37)	(4.89)	(3.67)	
2007-2017	8.02				0.21	5.28				0.05
	(2.71)					(2.98)				
	8.03	-0.56			0.23	5.27	0.82			0.07
	(2.63)	(0.59)				(3.14)	(1.34)			
	10.41	-0.38	-5.36		0.29	7.87	1.02	-5.89		0.12
	(2.60)	(0.66)	(1.95)			(3.15)	(1.37)	(2.50)		
	13.35	-0.19	-7.26	-5.26	0.35	11.88	1.29	-8.47	-7.17	0.18
	(2.80)	(0.70)	(1.79)	(1.39)		(3.47)	(1.37)	(2.31)	(2.13)	

Table A.16: Forecasting Exchange Rate Changes: US/UK

The dependent variable is the annualized change in the exchange rate (in logs) $(4/k)\Delta s_{t\rightarrow t+k}$ on a long position in the dollar over k quarters. The independent variables are the Treasury basis, x^{Treas}, the nominal Treasury yield difference $(y^{\$} - y^{*})$, the change in the Treasury basis Δx_t^{Treas}, and the lagged change in the Treasury basis Δx_{t-1}^{Treas}. Data is quarterly from 1970Q1 to 2017Q2. Heteroskedasticity and autocorrelation adjusted standard errors in parentheses.

	$\overline{x}^{Treas}$	$\Delta\overline{x}^{Treas}$	Lag $\Delta\overline{x}^{Treas}$	$y^{\$} - \overline{y}^{*}$	R^2
	Panel A: 1970-2017				
3 months	-2.01	1.73	-6.08	-3.03	0.06
	(4.38)	(1.26)	(4.68)	(3.01)	
1 year	0.51	1.02	-3.29	-2.20	0.04
	(3.18)	(0.88)	(2.10)	(1.36)	
2 years	3.72	0.92	-5.49	-3.51	0.09
	(2.16)	(0.59)	(1.70)	(1.04)	
3 years	7.51	1.04	-6.66	-4.24	0.28
	(1.63)	(0.42)	(1.37)	(0.87)	
	Panel B: 1970-2007				
3 months	-2.54	2.09	-4.52	-2.34	0.07
	(4.54)	(1.33)	(4.55)	(2.94)	
1 year	0.18	1.10	-3.29	-2.51	0.05
	(3.25)	(0.93)	(2.13)	(1.37)	
2 years	3.55	0.94	-5.35	-3.55	0.10
	(2.21)	(0.64)	(1.74)	(1.06)	
3 years	7.48	1.07	-6.67	-4.31	0.30
	1.69	(0.47)	(1.41)	(0.90)	
	Panel C: 2007-2017				
3 months	25.73	-9.84	-88.53	-28.34	0.55
	(11.39)	(2.88)	(20.56)	(16.67)	
1 year	22.28	-8.53	-0.10	10.54	0.45
	(7.57)	(2.55)	(7.25)	(7.78)	
2 years	10.12	-4.25	-8.06	4.99	0.33
	(12.25)	(1.47)	(9.26)	(7.62)	
3 years	8.03	-2.19	-3.64	1.33	0.22
	(6.92)	(0.88)	(5.41)	(3.99)	

D.8 KFW Bonds

Figure A.6 plots the basis for KfW bonds. KfW is a German issuer whose bonds are backed by the German government, so that they are near default free. KfW issues bonds in different currencies allowing us to compute the basis for the bonds of the same issuer, i.e., holding safety fixed, in different currencies. We compute the basis for KfW bonds using one-year yields on these bonds for Australia, Euro, UK, and Switzerland against the US. The yield data is from Bloomberg and corresponds to a fitted yield at the one-year maturity (one-year maturity bonds do not always exist). Clearly this measure is not as reliable as our Treasury basis measure which only uses information from traded instruments. Figure A.6 plots the cross-country mean KfW basis and the Treasury basis (cross-country mean for the same countries) over a sample with daily data from 2011Q2 to 2017Q2.

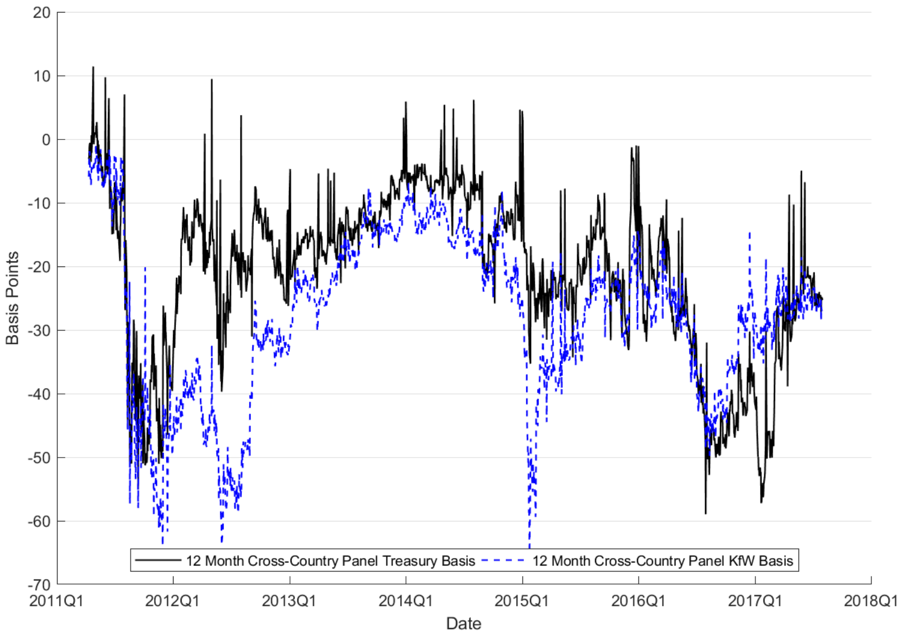

Figure A.6: KfW and Treasury Basis, 2011Q2 to 2017Q2