How Safe Are Safe Havens?*

International Post-Crisis Evidence

Preliminary version – comments welcome.

Sven Klingler
Suresh Sundaresan

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Abstract

Sovereign Debt issued by developed economies enjoyed a "safe-haven" status with bond yields below other proxies of the risk-free rate. But since the financial crisis, U.S. Treasury yields regularly exceed the risk-free rate measured as the fixed rate in corresponding overnight index swaps (OIS), violating text book arbitrage restrictions. We use data from the primary auctions market to construct estimates of demand shocks and document a strong link between sovereign debt yield spreads for different maturities and countries that is robust to using other demand or risk-free rate proxies and to accounting for quantitative easing policies of monetary authorities. While U.S. Treasury securities appear to have lost their safe-haven status, German sovereign debt retains its status.

*Klingler is with the Department of Finance, BI Norwegian Business School, Nydalsveien 37, NO-0442 Oslo, Norway. E-mail: sven.klingler@bi.no. Sundaresan is with Columbia Business School, 3022 Broadway, Uris Hall 401 New York, NY 10027. E-mail: ms122@gsb.columbia.edu. We are grateful to Arvind Krishnamurthy and Olav Syrstad for helpful comments and suggestions.

Introduction

U.S. Treasuries are arguably the worlds safest and most liquid financial assets and investors attach a "liquidity premium" or "convenience yield" to holding these assets (e.g. Longstaff (2004), Krishnamurthy and Vissing-Jorgensen (2012), or Nagel (2016)) which should push Treasury yields below other proxies for the risk-free rate. However, since the financial crisis, the spreads between the fixed rate in overnight index swaps (OIS) – a common proxy for the risk-free rate, in which a fixed rate is exchanged against the average overnight bank lending rate – and U.S. Treasury yields with the same maturity (henceforth OIS-Treasury spread) regularly drop below zero. Based on this observation, we challenge the notion that Treasuries enjoy a "safe haven" status with bond yields yields below other proxies of the risk free rate and link the diminishing Treasury premium to a fading demand for U.S. Treasuries.

To motivate our analysis, we document that OIS-Treasury spreads drop from positive to negative because of significant increases Treasury yields (not because of significant drops in OIS rates). We construct direct measures of Treasury demand from the primary auctions market and find that negative Treasury demand shocks coincide with drops in Treasury yield spreads. We confirm the link between our Treasury demand proxy and Treasury yield spreads in a regression analysis, controlling for Treasury supply, quantitative easing, and the level of the yield curve. A stronger U.S. dollar which makes foreign Treasury investments more costly can partly explain the decreasing Treasury demand. Putting our findings into an international perspective, we find that despite a similar impact of demand proxies, Germany has kept its safe-haven status while negative OIS-Treasury spreads occur regularly in Japan and the U.K.

We measure Treasury yield spreads against OIS rates which allows us to study a panel of spreads with six different maturities between 3 months and 5 years (dropping the 1-month spread which rarely turned negative).[1] The first demand proxy is the bid-cover ratio, total bids in a Treasury auction divided by the amount of new Treasuries at offer. We find that negative shocks to the bid-cover ratio put downward pressure on OIS-Treasury spreads. This finding is robust to using alternative measures, such as Libor-Treasury spreads, off/on-the-run spreads, and raw changes in Treasury yields. To mitigate reverse causality concerns, we investigate the impact of auction-based demand measures (which are observed during the course of a month) on month-end changes in OIS-Treasury spreads, effectively lagging the demand measures by several days.

Two alternative demand proxies are the fraction of the issued securities allocated to primary dealers and to foreign direct investors. Because primary dealers are obliged to participate in every auction, a higher primary dealer allocation suggests a weakening demand. By contrast, a higher allocation to foreign investors, who are a major investor class that holds up to 40% of all outstanding Treasuries during our sample period, suggests a stronger demand. In line with this intuition, we find a significant negative (positive) link between OIS-Treasury spreads and increases in primary dealer allocations (foreign allocations). All three demand proxies explain a sizable portion of the variation in OIS-Treasury spreads (the R^2 approximately doubles compared to using previously established proxies).

After having documented that a lower demand for Treasuries drives Treasury yield spreads down, we next investigate the possible causes of the weakening demand. While the massive post-crisis increase in Treasury supply might be related to the weakening demand, we uncover a link between a higher U.S. dollar and lower foreign Treasury holdings

[1]Finding a risk-free benchmark for computing Treasury yield spreads became more difficult after the financial crisis. We focus on maturities of 5 years or less because demand pressure for receiving fixed rates can push swap rates and OIS rates down (Klingler and Sundaresan (2018)). In the short end, the default of Lehman Brothers showed that high-quality short-term commercial papers (used by, among others, Krishnamurthy and Vissing-Jorgensen (2012)) are not entirely risk-free and new financial regulations pushed interest rates in term repurchase agreements up (Nagel (2016) uses term repos as benchmark).

that helps disentangling supply and demand effects. A higher U.S. dollar makes foreign Treasury investments more costly, thereby lowering the foreign Treasury demand. We utilize that idea in a two-stage least squares setting. In a first stage, we regress changes in our demand proxies on changes in the U.S. dollar (allowing for a different coefficient for bills and notes). We add changes in the interest rate differential between the U.S. dollar Libor (swap) rate and IBOR (swap) rates in the G-10 currencies to strengthen the power of our instruments. Changes in the U.S. dollar and the interest rate differential affect the foreign demand for Treasuries while there is no obvious link to OIS-Treasury spreads or Treasury supply. Our results are robust to this test.

To put our findings into an international perspective, we also study OIS-Treasury spreads in Germany, Japan, and the U.K. Comparing the level of OIS-Treasury spreads, Germany stands out as the only country that rarely experience negative post-crisis OIS-Treasury spreads. Despite this difference, demand effects affect German and Japanese OIS-Treasury spreads in a similar way as they do for the U.S. while supply effects, measured by the debt-to-GDP ratio have limited explanatory power in these countries.

We conclude by exploring other possible explanations for negative U.S. Treasury spreads and perform a variety of robustness checks. First, we investigate the link between OIS-Treasury spreads and U.S. CDS premiums, documenting a significant negative relationship that is only driven by the weeks around the two debt ceiling debates in 2011 and 2013. Controlling for CDS premiums or other variables such as implied volatility or U.S. recession probabilities leaves the link between our demand proxy and OIS-Treasury spreads intact. Second, we construct an alternative proxy for Treasury demand that is not based on auction data – weekly primary dealer's Treasury holdings divided by the amount of Treasuries outstanding. This proxy is available at the same weekday for bills and notes but only allows us to distinguish between bills, non-bills with less than 3 years to maturity, and non-bills with less than 6 and more than three years to maturity. In line with our previous results for primary dealer auction allocations, we find that increases in primary dealer Treasury holdings correspond to decreasing OIS-Treasury spreads.

Contributions to the Literature

We illustrate a link between Treasury demand and Treasury yield spreads that can explain the diminishing/vanishing post-crisis convenience yield. Our demand-based explanation supplements Nagel (2016) who argues that higher interest rates correspond to a higher opportunity cost of holding cash, thereby increasing the convenience yield of holding Treasuries. While Nagel (2016) uses an indirect proxy for Treasury demand, we construct direct demand proxies which explain various post-crisis Treasury yield spreads with maturities between 3 months and 5 years. In contrast to our demand-based explanation, Krishnamurthy and Vissing-Jorgensen (2012) and Greenwood, Hanson, and Stein (2015) document a link between the convenience yield of U.S. Treasuries and the Treasury supply. More recently, Krishnamurthy and Vissing-Jorgensen (2011) and Pelizzon, Subrahmanyam, Tomio, and Uno (2018) document that supply shocks in the form of central bank government bond purchases affect bond yields. While the Treasury supply is an important driver of the convenience yield, we find that changes in the demand for Treasuries are even more important.

We document a significant decline in post-crisis Treasury yield spreads and offer a *demand-based explanation* for the vanishing convenience yield. The post-crisis cheapening of U.S. Treasuries resonates with Du, Im, and Schreger (2018) who construct a measure of relative Treasury convenience yield (relative to other G10 countries) based on deviations from the covered interest rate parity (CIP) that points to a post-crisis decline in Treasury convenience yield for maturities of 5 and 10 years. In contrast to our demand-based explanation, Du et al. (2018) link their convenience yield measure to the difference in debt-to-GDP ratios and policy rates between the U.S. and the other countries. We also uncover a negative relationship between the U.S. dollar and foreign Treasury demand, adding to the findings of Jiang, Krishnamurthy, and Lustig (2018) who use a CIP-based measure of Treasury convenience yield to predict changes in the U.S. Dollar. Avdjiev, Du, Koch, and Shin (2017) document a strong negative relationship between the U.S. dollar and the cross-currency basis and we add to their findings by uncovering a negative relationship between the U.S. Dollar and foreign Treasury holdings.

Our main proxies for Treasury demand come from Treasury auctions and previous studies have shown that Treasury yields increase before an auction date and decrease afterwards (see Lou, Yan, and Zhang (2013) for the U.S. and Beetsma, Giuliodori, de Jong, and Widijanto (2016), Beetsma, Giuliodori, Hanson, and de Jong (2018), Sigaux (2017) for Europe). We extend these studies to Treasury yield spreads and find a strong link between yield spreads and the auction demand, thereby adding to the literature on auction date effects. While the bid-cover ratio is the most important headline measure, we also use the auction allocation to primary dealers and construct a new measure of relative primary dealer holdings, calculated as the ratio of primary dealer Treasury holdings to total Treasury outstanding. By linking primary dealer's relative Treasury holdings to Treasury yield spreads, we add to the finding of Fleming and Rosenberg (2007) who document a link between primary dealer Treasury holdings and auction allocations. To the best of our knowledge, our paper is the first to link Treasury yield spreads to foreign Treasury demand.

The focus of our paper is on OIS-Treasury spread and we show that negative OIS-Treasury spreads are a near-arbitrage opportunity. In that sense, the post-crisis Treasury cheapening is related to a large literature on fixed income mispricings (Krishnamurthy (2002), Duarte, Longstaff, and Yu (2007), Fleckenstein, Longstaff, and Lustig (2014), Junge and Trolle (2014), among others), Treasury illiquidity and relative Treasury mispricings (Goyenko, Subrahmanyam, and Ukhov (2011), Fontaine and Garcia (2012), Hu, Pan, and Wang (2013), Musto, Nini, and Schwarz (2015), Adrian, Fleming, and Vogt (2017)), as well as post-crisis deviations from the law of one price (e.g. Boyarchenko, Eisenbach, Gupta, Shachar, and Van Tassel (2018), Du, Tepper, and Verdelhan (2018), Pelizzon et al. (2018), among many others). Tighter post-crisis bank regulations lower the profitability of small arbitrage opportunities (Boyarchenko et al. (2018)) and can explain the persistent negative OIS-Treasury spreads. Instead of studying the post-crisis constraints for arbitrageurs, we show that the fundamental reason for drops in OIS-Treasury spreads is a drop in the demand for Treasuries.

1 Institutional Background

This section provides the background and motivation for our analysis. After describing OIS-Treasury spreads, we give some institutional background on the OIS and Treasury markets. We then describe our approach to measuring the demand for Treasuries.

1.1 OIS-Treasury Spreads

In Figure 1, we plot weekly averages of OIS-Treasury spreads with 3 months, 6 months, 2 years, and 5 years to maturity (omitting 1-year and 3-year spreads for better visualization). The four vertical red lines correspond to the dates when Lehman Brothers defaulted, Standard & Poor's downgraded the credit rating of the U.S. (right after the end of the first debt ceiling crisis), the end of the second debt ceiling crisis, and the passing of the new tax regulation in congress. As we can see from the figure, OIS-Treasury spreads peaked before the default of Lehman Brothers and plunged after the financial crisis, stabilizing at a lower post-crisis level. The most significant post-crisis drop in OIS-Treasury spreads coincides with the U.S. tax reform in November 2017, when OIS-Treasury spreads with all four maturities dropped sharply and eventually turned negative. By comparison, the drops in OIS-Treasury spreads around the debt ceiling crises are smaller, despite causing fears about a potential technical default of the U.S.[2]

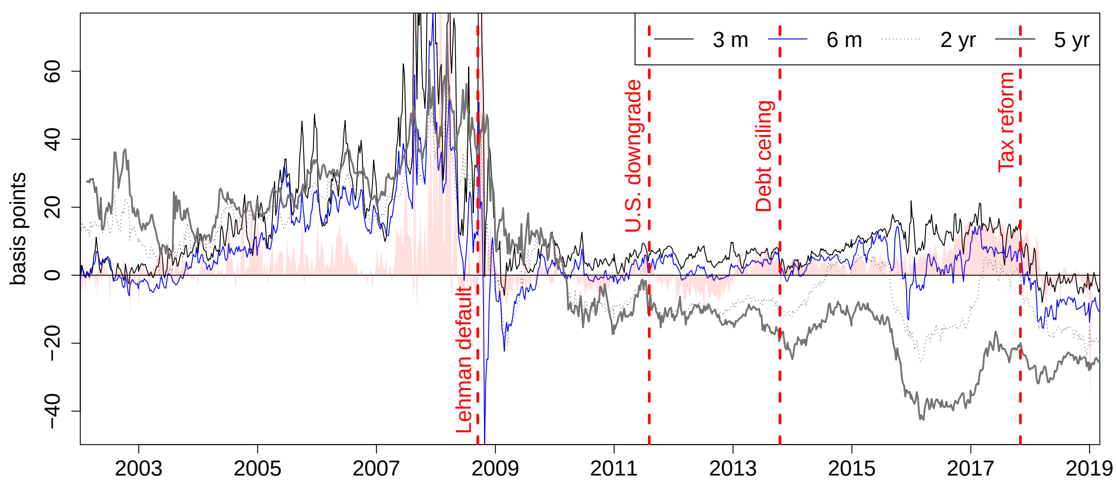

Figure 1: **OIS-Treasury spreads for different maturities.** This figure shows weekly averages of the spread between OIS and Treasury securities with the same maturity (taking the different daycount conventions into account), ranging from 3 months to 5 years. The red shaded area is the spread between the effective federal funds rate and the overnight repo rate, measured as the GCF repo rate before October 2012 and a volume-weighted average of triparty repo rates and GCF rates after. The dashed vertical lines correspond to the date when Lehman Brothers defaulted (Sep 15, 2008), the date when Standard & Poors downgraded the U.S. (Aug 5, 2011), the resolution of the second debt ceiling crisis (Oct 16, 2013) and the passing of the new tax reform (Nov 2, 2017).

[2] We discuss this fear of a technical default and the link between OIS-Treasury spreads and potential U.S. credit risk in more detail in Section 5.

The red-shaded area in Figure 1 is the spread between the effective federal funds rate (EFFR), which is the floating rate in an OIS, and the overnight repo rate, which captures the average rate at which a Treasury position can be financed.[3] The following argument provides a theoretical link between EFFR-repo and OIS-Treasury spreads. If OIS-Treasury spreads are negative, an arbitrageur could purchase the Treasury security, finance it at the repo rate, and engage as fixed payer in an OIS. This combination of transactions allows him to receive both the EFFR-Repo spread and the negative OIS-Treasury spread. The possibility of negative EFFR-Repo spreads can cause the arbitrageur to lose money and turns the strategy into a "risky arbitrage" trade. We provide a more detailed description of this near-arbitrage strategy as well as an approximation of the returns and Sharpe ratios of the strategy in Appendix B.

[3]To obtain this average rate, we construct a volume-weighted repo index, using repo volumes from the New York FED, triparty repo rates from BNY Mellon, and GCF repo rates from DTCC, supplemented with repo rates from Bloomberg before 2005. After 2017, we use the secured overnight funding rate (SOFR) as proxy for Treasury financing costs. Unfortunately, triparty repo rates are only available from October 2012 on, but because the spread between GCF and triparty repo rates was small before the introduction of the leverage ratio (see, for example Duffie (2017)), the GCF repo rate is a good proxy for the aggregate repo rate in the earlier part of the sample.

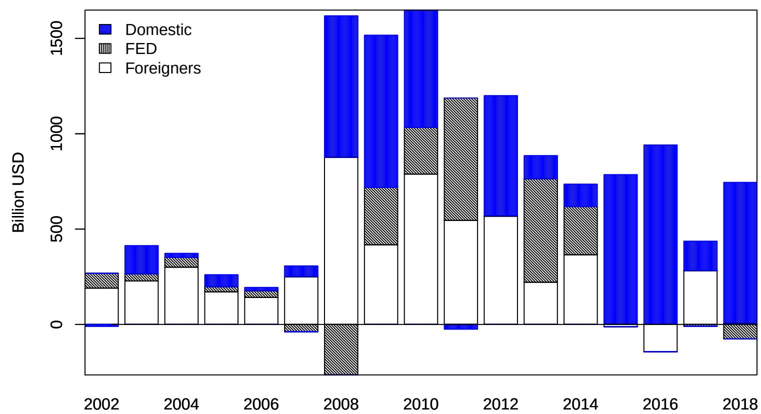

Figure 2: **Changes in Treasury debt holdings.** This figure shows annual changes in U.S. Treasury holdings (including non-marketable debt), for three main holders: Foreign investors, official holdings by the FED, and other holdings by domestic investors. If all three changes are positive, the the level of the bar shows the total increase in Treasury debt. Otherwise the total increase in Treasury debt corresponds to the difference between the positive and negative numbers (Datasource: Financial accounts of the U.S.)

To get a better understanding of the the two markets, we start by approximating the size of the OIS market. Since 2012 the Depository Trust & Clearing Corporation (DTCC) provides weekly breakdowns of the OIS gross notional by currency and year of maturity. We use these data to approximate the gross volume of U.S. dollar denominated OIS contracts with less than one year to maturity (contracts maturing within the reporting year), contracts with maturities between 1-5 years (contracts maturing between the next year and 5 years from the reporting year), and contracts with maturity over 5 years from the reporting year. Panel (a) of Figure **??** shows yearly averages of these number, illustrating that gross OIS volume doubled from approximately $10 trillion in 2012 to more than $20 trillion in 2018 despite the shirnking FED funds market. Moreover, the figure shows that OIS volumes for further than 5 years to maturity are relatively small in comparison to shorter maturities. We therefore drop OIS-Treasury spreads with more than 5 years to maturity from our analysis.[4]

[4]Another rationale for dropping longer maturities from our investigation is that demand pressure by

We next summarize recent changes in Treasury holdings in Panel (b) of Figure **??**, which shows the annual changes in Treasury debt holdings (including both marketable and non-marketable debt) for three major investor classes: foreigners, the FED, and domestic investors. Before the financial crisis, foreign investors were the predominant investor class to absorb increases in Treasury debt. A combination of foreign and domestic investors absorbed the huge increase in Treasury debt during the 2008 financial crisis. After the financial crisis, Treasury issuance continued at high levels and domestic investors absorbed more of the increase. Most noticeable, in 2015 and 2016 domestic investors increased their Treasury holdings while foreigners reduced their positions. We later explore the fact that foreign investors are a predominant investor in U.S. Treasuries.

1.2 Measuring Demand for Treasuries

We measure the demand for Treasury debt by constructing a proxy based on the bidding behavior of auction participants in the primary market. In a Treasury auction, each bidder submits the quantity and yield at which he wants to purchase the auctioned security.[5] Aggregating all bids and dividing them by the issuance volume gives the most-widely used measure of the demand in an auction – the bid-cover ratio. To extract information about Treasury demand, market participants compare the bid-cover ratio of the current auction to the past 3–4 bid-cover ratios in similar auctions (see, for example, inTouch capital markets: "US Treasuries – Reading Auction Results"). We follow this practice and define bid-cover

end-users of derivatives can lower swap rates with longer maturities (Klingler and Sundaresan (2018)).

[5]More precisely, all U.S. Treasury auctions in our sample are sealed-bid uniform price auctions in which all winning bidders pay exactly the same price.

shocks as:

$$BC_t^s := \log\left(\frac{BC_t}{\frac{1}{4}(BC_{t-1} + BC_{t-2} + BC_{t-3} + BC_{t-4})}\right). \tag{1}$$

In line with our approach, anecdotal evidence from a July 2018 Bloomberg article ("Where Were You During the Great T-Bill Massacre of 2018?") suggests that a bid-cover ratio below past year's average put downward pressure on Treasury yields.

The drawback of the the bid-cover ratio is that dealers can manipulate it, for example, by bidding at a rate well below the market rate. An alternative measure of the auction outcome are the auction allocations to different investor classes. A higher allocation to foreign direct bidders suggests a stronger demand for Treasuries. In contrast, a higher allocation to primary dealers suggests a bad auction outcome because unlike other auction participants, "the New York FED will expect a primary dealer to bid in every auction" (see Federal Reserve Bank of New York (2016)). Hence, if the demand by other direct bidders (such as foreign officials) drops, the share purchased by primary dealers increases. We use these measures to perform robustness analysis.

Table 1 provides summary statistics of U.S Treasury auctions for the post-crisis sample period. We first note that Treasury bill auctions (weekly 3 and 6-month and monthly for 1-year auctions) are more regular than note auctions, which occur on average every 30 calendar days but with a standard deviation of 3-4 days. The average bid-cover ratio ranges from 4.18 for 6-month bills to 2.64 for 5-year notes. By contrast, the primary dealer allocation is highest for the 3-month bills and lowest for the 5-year notes and the allocation to foreign bidders is lower in the short end than in the long end. We also construct a supply proxy for each maturity by computing the dollar amount of Treasuries with the same original time-to maturity and report these figures, which range from \$ 0.3 trillion for 1-year bills to \$ 1.96 trillion for 5-year notes, under Outst (\$ trn). The final summary statistic in Table 1 is the average distance of the auction from the last trading day in the same month. As we can see from the table, this distance ranges from 2.55 days for 3 and 6 month bills to 20.61 days for 3-year notes.

Table 1: **Descriptive statistics for U.S. Treasury auctions.** This table provides summary statistics of Treasury auctions for maturities between 3 months and 5 years in the July 2009 to September 2018 sample period. Under *summary of auction statistics*, the averages of the calendar days between auctions, the bid-cover ratios, the fraction allocated to primary dealers and foreign investors, the outstanding amount of the specific security type, and the average distance from the last trading day in the month are reported. Under *Regression of* BC^s, we report the coefficients of regressing bid-cover shocks on precentage changes in outstanding amounts and shocks to the percentage primary dealer allocations, omitting the intercept for brevity. The numbers in parantheses are heteroskedasticity-robust standard errors.

		Summary of auction statistics						Regression of BC^s		
	# Obs	Days between	Bid-Cover	% PD	% Forgn	Outst (\$ trn)	Dist m-end	$\Delta Outst(\%)$	$(\%PD)^s$	R^2
3 m	469	7.00	4.06	61.8	7.5	0.41	2.55	-0.57	-0.14	0.12
		(0.50)	(0.62)	(10.9)	(5.9)	(0.08)	(1.56)	(0.29)	(0.02)	
6 m	469	7.00	4.18	51.0	25.4	0.74	2.55	-1.12	-0.14	0.16
		(0.50)	(0.68)	(9.8)	(9.4)	(0.10)	(1.56)	(0.56)	(0.02)	
1 yr	117	28.00	4.02	56.7	19.0	0.30	13.11	-0.57	-0.27	0.30
		(0.42)	(0.62)	(10.3)	(9.2)	(0.03)	(8.29)	(0.53)	(0.04)	
2 yr	107	30.38	3.23	44.4	17.3	0.82	5.29	0.21	-0.14	0.17
		(4.06)	(0.40)	(10.8)	(6.2)	(0.11)	(2.56)	(0.73)	(0.02)	
3 yr	108	30.48	3.15	43.4	20.4	1.02	20.61	0.50	-0.14	0.17
		(3.09)	(0.29)	(9.1)	(8.0)	(0.21)	(2.41)	(0.21)	(0.03)	
5 yr	107	30.38	2.64	37.2	18.5	1.96	4.28	1.65	-0.19	0.33
		(3.77)	(0.23)	(9.7)	(7.7)	(0.30)	(2.55)	(0.75)	(0.03)	

To get a better idea of the relationship between bid-cover ratios, auction allocations, and Treasury supply, we next regress bid-cover shocks on percentage changes in Treasuries outstanding and shocks to the primary dealer allocation. In line with the intuition that primary dealers purchase more Treasuries in bad auctions, Table 1 shows a strong negative relation between the dealer allocation – the share that broker-dealers get in an auction – and the bid-cover ratio. By contrast, the intuition that a higher supply leads to a lower demand is only supported for Treasury bills, where percentage increases in the outstanding amounts tend to correspond to negative bid-cover shocks.

2 Motivating Evidence

In this section, we first document that drops of OIS-Treasury spreads to negative values are driven by cheapening Treasuries, that is by increases in Treasury yields as opposed to decreases in OIS rates. Thereafter, we provide non-parametric evidence for the link between OIS-Treasury spreads and Treasury demand (measured as shocks to the bid-cover ratio). We conclude by illustrating a link between foreign Treasury holdings and the U.S. dollar.

2.1 Increasing Treasury Yields and Negative OIS-Treasury Spreads

The OIS-Treasury spread can drop due to a drop in the OIS rate or because of an increase in the Treasury yield. To understand which part drives OIS-Treasury spreads negative, we execute an event study analysis, using weekly observations of spreads with maturities between 3 months and 5 years. For each maturity we define weeks in which the OIS-Treasury spread drops below zero as event weeks and then separately compute changes in the OIS rate and Treasury yield. Aggregating events for the six maturities in our July 2009 – September 2018 sample period, gives 86 weeks in which OIS-Treasury spreads drop from positive to negative. Table 2 shows the average change in OIS rates and Treasury yields one week before $(t-1)$, in the week (t), and one week after $(t+1)$ the spread turns negative. To test if the increases in Treasury yields are significant, we also compute and report heteroskedasticity robust t-

statistics for all averages. To highlight the focus of our analysis, mark the average change in Treasury yields in weeks t with a grey bar.

The first column of Table 2 shows that OIS-Treasury spreads drop from positive to negative because of increases in Treasury yields. On dates when the OIS-Treasury spread drops from positive to negative, the OIS increases, on average, by 1.57 basis points while the Treasury yield increases by 4.92 basis points. Hence, we can reject the hypothesis that OIS-Treasury spreads become negative because of decreases in OIS rates. In columns 2 and 3 of Table 2 we repeat our analysis for bills and notes separately, confirming that for both bills and notes OIS-Treasury spreads drop from positive to negative because of increases in Treasury yields. In both cases, the increases in Treasury yields is statistically significant while we do not observe a significant drop in OIS rates. We next repeat our analysis for the Jan 2002 – Jun 2009 sample period in which we observe 39 drops of OIS-Treasury spreads from positive to negative. Column 4 reports the results of this test, showing an opposite pattern compared to the results for the post-crisis period: OIS-Treasury spreads drop because of drops in OIS not because of increases in Treasury yields. This finding shows that, despite negative pre-crisis OIS-Treasury spreads, the Treasury cheapening is a recent phenomenon.

We conclude our analysis by replacing event weeks with weeks in which we observe drops in OIS-Treasury spreads that are below the 5% quantile. The 5% quantile is computed separately for each maturity and over the entire post-crisis sample period. This test ensures that we have a large number of events for each individual maturity. Columns 5 and 6 of Table 2 confirm our findings: sharp drops in OIS-Treasury spreads are driven by increasing Treasury yields while we do not observe significant drops in OIS rates.

Table 2: **OIS rates and Treasury yields around decreases in spreads.** This table reports time series averages of weekly changes in OIS rates and Treasury yields around weeks when OIS-Treasury spreads decrease from positive to negative (panels 1–4) and weeks when OIS-Treasury spreads decrease more than their 5% quantile (panels 5 & 6). The panel labelled *Pre* is for the Jan 2002 – Jun 2009 sample period, all other panels are for the July 2009 – Sep 2018 period. The sample comprises OIS rates and Treasury yields with 3 months, 6 months, 1 year, 2 years, 3 years, and 5 years to maturity. $(t-1)$, t, and $(t+1)$ indicate that the observations are one week before, during, or one week after the event week, respectively. $\times UST$ and $\times OIS$ indicate that the averages are changes in Treasury yields and OIS rates, respectively. Heteroscedasticity robust t-statistics are reported in parenthesis. ***, **, and * denote significance at a 1%, 5%, and 10% level, respectively.

	Drop +/−				Drop $> q^{5\%}$	
	All	Bills	Notes	Pre	Bills	Notes
$(t-1)\times OIS$	−0.57	0.45	−2.89**	0.44	0.95**	1.23
	(−1.03)	(1.38)	(−1.98)	(0.17)	(2.28)	(0.80)
$(t-1)\times UST$	−0.52	1.27**	−4.40***	−0.24	−1.00*	−0.27
	(−0.70)	(2.11)	(−2.80)	(−0.09)	(−1.70)	(−0.18)
$t\times OIS$	1.57**	0.38	4.21**	−4.70***	0.47	−1.02
	(2.30)	(1.15)	(2.05)	(−4.56)	(0.87)	(−0.91)
$t\times UST$	4.29***	3.02***	7.19***	1.44	6.11***	4.38***
	(6.02)	(7.44)	(3.46)	(0.91)	(10.44)	(4.02)
$(t+1)\times OIS$	−0.51	0.12	−2.28	−2.18	1.52***	−0.74
	(−0.88)	(0.35)	(−1.22)	(−1.44)	(3.08)	(−0.67)
$(t+1)\times UST$	−0.48	0.15	−2.21	−1.34	0.20	−2.74**
	(−0.70)	(0.32)	(−1.04)	(−0.78)	(0.27)	(−2.45)
$\mathbb{E}[\Delta OIST\|t]$	-2.75	-2.63	-3.05	-6.22	-5.67	-5.38
Num. evts.	87	61	26	39	75	75

2.2 OIS-Treasury spreads and the Demand for Treasuries

In this section, we investigate the link between OIS-Treasury spreads and Treasury demand based on non-parametric tests. As a first step, we plot the level of OIS-Treasury spreads with maturities between 3 months and 5 years against the level of the corresponding bid-cover ratios. Figure 3 illustrates the negative association between the two variables: OIS-Treasury spreads are lower when the bid-cover ratio is low. Because of the non-stationarity of the two variables and because market participants infer the auction-based demand from comparing the current level of the bid-cover ratio to levels in the recent past, we focus our main analysis on changes in OIS-Treasury spreads and bid-cover shocks as defined in Equation (1).

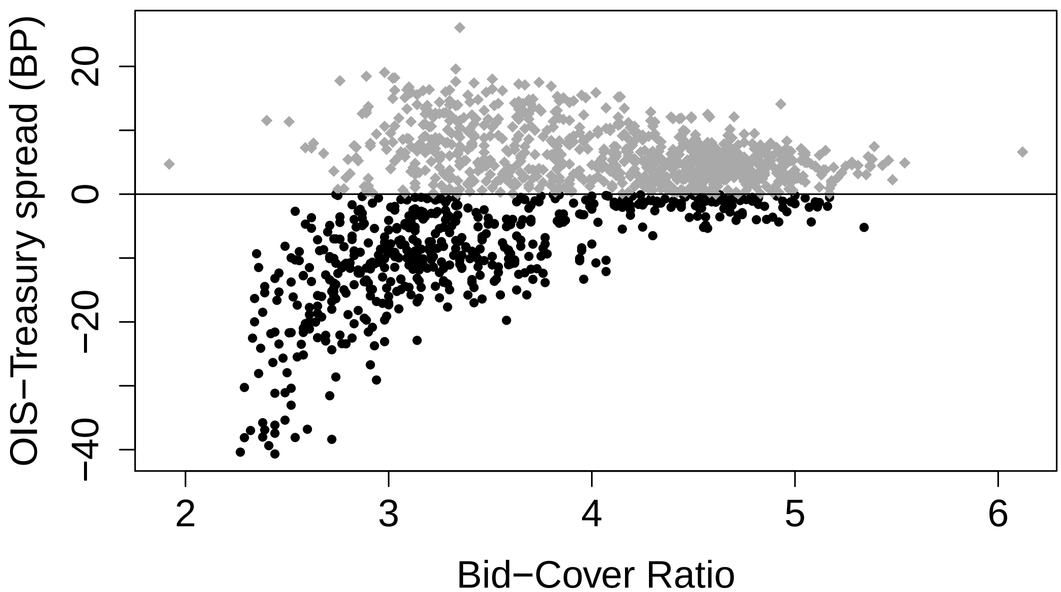

Figure 3: **Link between OIS-Treasury spreads and demand variables.** This figure illustrates the link between OIS-Treasury spreads with maturities between 3 months and 5 years and bid-cover ratios for for newly-issued Treasury securities with the same maturity as the OIS-Treasury spread. The blue line indicates the polynomial fit (of degree two) between the two variables. The sample period is July 2009 to October 2018.

To that end, we next test if the distribution of changes in OIS-Treasury spreads is different when there is an increase in demand compared to a decrease in demand. The first row of Table 3 shows that, on average, OIS-Treasury spreads decrease by an average of -0.53 basis points and increase by 0.39 basis points, conditional on negative or positive shocks to the bid-cover ratio. The difference in means is 0.92 basis points and a t-test confirms the statistically significant at a 1% level (t-statistic of -6.11). In addition, the p-value a Kolmogorov-Smirnoff test is below 0.01%, rejecting the hypothesis that the distribution of OIS-Treasury spreads conditional on negative demand shocks is greater than the distribution for positive demand shocks. Moreover, approximately 50% of the observations in our sample of 1377 OIS-Treasury spread changes correspond to negative bid-cover shocks.

Table 3: **Link between Treasury yields and Treasury supply & demand.** This table compares changes in OIS-Treasury spreads from one auction date to the next for different subsamples. In row 1 the sample is split into one set where the bid-cover ratio is higher than the average bid-cover ratio in the past four auctions and one set where the bid cover ratio is lower than in the past four auctions. In rows 2 and 3 we consider the subsample of dates on which the outstanding amount of the individual securities increased or decreased. The last row compares changes in OIS-Treasury spreads conditional on increases or decreases in outstanding amounts. We test whether the two samples are different either by using a two-sided t-test or by using a Kolmogorov-Smirnoff test where the null hypothesis is that the low demand sample is lower than the high demand sample. ***, **, and * indicate significance at a 1%, 5%, and 10% level respectively. The sample period is July 2009 to September 2018.

	Bad	Good	Difference	(t-stat)	KS-test p-val	N	% bad shock
BC^{shock}	-0.45	0.34	0.79***	(-5.39)	0.000***	1415	0.50
$\text{BC}^{shock} \times \mathbb{1}_{\Delta Outst>0}$	-0.51	0.44	0.95***	(-4.52)	0.001***	778	0.50
$\text{BC}^{shock} \times \mathbb{1}_{\Delta Outst\leq 0}$	-0.38	0.22	0.60***	(-2.96)	0.009***	637	0.51
Δ Outst	-0.03	-0.09	-0.06	(0.38)	0.115	1415	0.55

To distinguish supply shocks from demand shocks, we construct two subsamples conditional on increases or decreases in the outstanding amount of Treasury securities with the specific maturity and repeat our analysis. As we can see from the second and third row of Table 3, the difference between OIS-Treasury changes conditional on negative bid-cover shocks and positive bid-cover shocks is 1.03 basis points for the subsample of increasing supply and 0.78 for the subsample of decreasing supply. In both cases, the difference is statistically significant at a 1% level (for both the t-test and the Kolmogorov-Smirnov test), suggesting that our demand proxy contains information not captured by the raw supply variables. Finally, changes in the outstanding amount of individual securities do not significantly influence OIS-Treasury spreads. We therefore use aggregate changes in Treasury bills and Treasury notes outstanding in our following regression analysis.

2.3 Foreign Treasury Holdings and the Dollar

Figure 4 illustrates the link between the percentage of all foreign Treasury holdings in month t and the value of the U.S. dollar in month $t-1$. Foreign Treasury holdings are the amount of Treasuries held by foreign officials, divided by the total volume of Treasuries outstanding and the value of the U.S. dollar is proxied as the trade-weighted dollar index. A higher dollar makes foreign Treasury investments more costly, which can explain the negative association between the two variables.

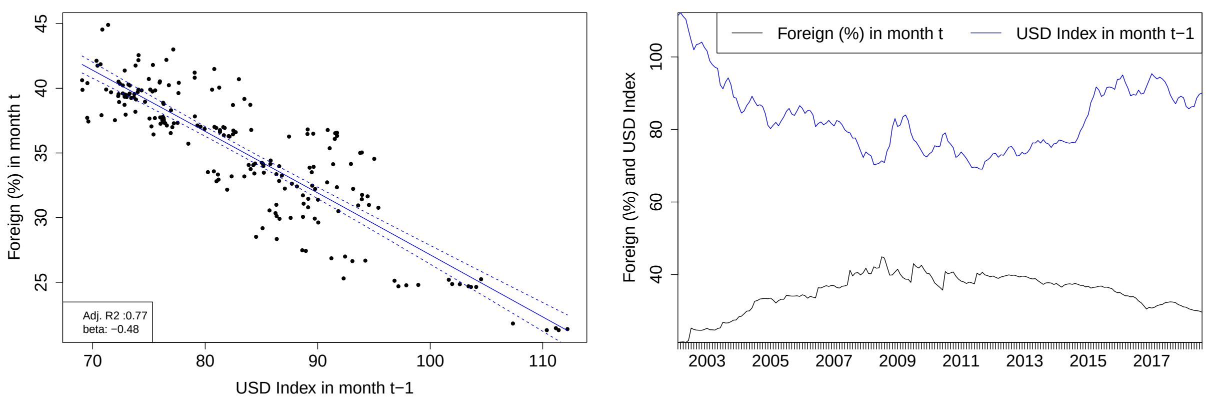

Figure 4: **Link between Foreign Treasury holdings and the U.S. Dollar** This figure illustrates the link between foreign Treasury holdings, measured as a fraction of total Treasury securities outstanding, and the trade-weighted U.S. dollar against the major foreign currencies. The sample period is January 2002 to October 2018 (datasources: TIC data and FED)

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3 Treasury Demand and Treasury Yield Spreads

In this section, we use regression analysis to establish the demand for Treasuries as key driver of Treasury yield spreads, proceeding in three steps. First, we use the bid-cover ratio as demand proxy and study changes from one auction date to the next. Second, we analyze the link between month-end changes in OIS-Treasury spreads and different lagged auction-based demand proxies. Finally, we use a two-stage least squares approach to alleviate the simultaneity bias concern.

3.1 Link to Bid-Cover Ratios

In our first test, we compute changes in Treasury yield spreads from one auction date to the next. Doing so enables us to separate the demand shocks measured on the auction date from auction concession effects (Lou et al. (2013)) and leads to an unbalanced panel with larger gaps between observations for longer maturities (a concern we address in the following section). We then regress changes in our panel of 3-months to 5-year OIS-Treasury spreads on Bid-Cover shocks ($BC_{i,t}^{shock}$, as defined in Equation (1)). In all regressions, we control for changes in the logarithm of the outstanding debt-to-GDP ratio ($\log(\frac{Outst}{GDP})$), measured as bills-to-GDP for 3 months to 1 year maturities and notes-to-GDP for the 2 year to 5 year maturities. We aggregate supply shocks across bills and notes because changes in the supply of individual securities have limited explanatory power (see Table 3). In addition, we control for changes in the short rate (a proxy for the opportunity cost of money Nagel (2016)) and changes in the EFFR-Repo spread (a proxy for the underlying no-arbitrage driver). Because of regular month-end spikes in the EFFR, we use the 1-month OIS rate as proxy for the short rate and use the 3-day average EFFR-Repo spread to mitigate the impact of calendar-day effects.

Panel (1) of Table 4 shows that there is a strong link between demand shocks and OIS-Treasury spreads. One unit of the bid-cover shock corresponds to an 8.05 basis point increase in the OIS-Treasury spread (t-statistic of 7.01). In addition, increasing Treasury supply

Table 4: **Link between Treasury yields and bid-cover ratios.** This table shows the results of various regressions of Treasury yield spreads on shocks to the bid-cover ratio, controlling for the ratio of bills-to-GDP or notes-to-GDP, changes in the 1-months OIS rate, and changes in the spread between EFFR and repo rate. In panels (1)-(3) the dependent variable is the OIS-Tresaury spread, utilizing our full sample of OIS-Treasury spreads with maturities between 3 months and 5 years, the sub-sample of Treasury bills, and the subsample Treasury notes, respectively. The dependent variable in Panel (4) is the Libor-Treasury spread, measured as Libor rate minus Treasury yield for maturities up to one year, and as swap rate minus Treasury yield for longer maturities. The dependent variable in Panel (5) is the on-the-run off-the run spread. In Panels (6) and (7) we analyze changes in the Treasury yields and changes in the OIS rates, respectiverly. All specifications include maturity-fixed effects. The numbers in parantheses are heteroskedasticity robust t-statistics. ***, **, and * indicate significance at a 1%, 5%, and 10% level respectively. The sample period is July 2009 to September 2018.

	OIS-Treasury spreads			Other measures			
	(1) All	(2) Bills	(3) Notes	(4) Lib/T	(5) Off/On	(6) UST	(7) OIS
Intercept	0.06	0.15	0.23	−0.49	−0.05	0.67	0.73
	(0.20)	(0.50)	(0.74)	(−0.78)	(−0.22)	(1.21)	(1.47)
BC^{shock}	8.05***	8.93***	5.87**	7.76***	4.66***	−17.56***	−9.48***
	(7.01)	(7.11)	(2.13)	(4.09)	(3.58)	(−5.93)	(−3.47)
$\Delta\log(\frac{Outst}{GDP})$	−26.61***	−23.12***	−55.28**	−23.69**	−13.98***	26.78**	−1.24
	(−5.11)	(−4.38)	(−2.37)	(−2.27)	(−3.04)	(2.00)	(−0.11)
ΔFF	−6.27	−11.56*	−4.76	−8.66*	1.89	65.91***	58.86***
	(−1.63)	(−1.69)	(−1.05)	(−1.70)	(0.76)	(6.56)	(6.48)
Δ FF-R	10.33***	10.22***	9.95	15.33***			
	(4.04)	(3.68)	(1.61)	(3.76)			
R^2 without	0.05	0.06	0.02	0.03	0	0.06	0.05
Adj. R^2	0.09	0.12	0.03	0.05	0.01	0.08	0.06
Num. obs.	1415	1084	331	1271	1415	1415	1415

lowers the OIS-Treasury spread while, in line with the arbitrage arguments of Section 1, an increase in the EFFR-Repo spread is associated with an increase in the OIS-Treasury spread. Note that demand shocks explain a sizable portion of the variation in OIS-Treasury spreads: The R^2 in regression (1) is 9% and dropping bid-cover shocks from the regression causes the R^2 to drop to 5%.[6]

We conclude our analysis of OIS-Treasury spreads by analyzing the sub-sample of Treasury bills and Treasury notes separately. As we can see from Panels (2) and (3), bid-cover shocks are highly significant for OIS-Treasury bill spreads and less so for OIS-Treasury note spreads. We attribute the lower significance for Treasury notes to the longer, less regular time between note auctions and analyze monthly changes of all spreads in Section 3.2 below.

We next analyze two alternative Treasury yield spreads. First, we use Libor rates as benchmarks for Treasury bills and Libor swap rates for Treasury notes. Libor rates are a noisy proxy for the risk-free rate because they contain a default risk premium. Despite this noise, Panel (4) shows a strong relation between bid-cover shocks and Libor-Treasury spreads. Second, the spreads between off-the-run and on-the run Treasuries, which capture the liquidity premium and specialness of the most recently issued Treasury security (see, for example, Greenwood et al. (2015) or Nagel (2016)). A diminishing demand for Treasuries should lead to a lower spread between off-the-run and on-the-run securities because the on-the-run bonds become less special. In line with this argument, Panel (5) shows that a positive bid-cover shock corresponds to increasing spreads, although the statistical and economical significance of the shocks is lower compared to OIS-Treasury spreads.[7]

[6] We discuss the impact of additional control variables in Appendix C and find that the strong significance of bid-cover shocks is robust to adding a variety of controls, such as, the VIX index, dealer constraints, and U.S. CDS premiums or recession probabilities.

[7] We drop the EFFR-Repo spread from this specification because there is no economic intuition for why this spread should be relevant.

Finally, we study the effect of bid-cover shocks on the raw changes in Treasury yields without computing yield spreads. This approach has the advantage that we do not benchmark Treasury yields on a proxy for the risk-free rate but the drawback that we do not control for term premiums and interest rate risk in Treasury yields. Panel (6) shows that bid-cover shocks remain statistically significant for raw changes in Treasury yields and the coefficient β^{BC} changes from 8.05 in specification (1) to -17.56 (the sign changes due to the fact that we subtract Treasury yields from other benchmarks while we now consider raw yields). We repeat our analysis for raw changes in OIS rates and find that bid-cover shocks also affect changes in OIS rates with the same sign as Treasury yields but with a lower statistical and economical significance (the R^2 of a regression with and without bid-cover shocks is 6%). Subtracting the coefficient on Treasury yields from the coefficient on OIS rate, approximately corresponds to the β^{BC} in panel (1).

3.2 More Auction-Based Measures

In this section, we test the robustness of our main analysis against three concerns. First, we used an unbalanced panel of changes from one auction date to the next in Section 3.1. Second, even though auction results are available before the end-of-day OIS-Treasury spread, a longer lag between the two variables ensures that OIS-Treasury spreads respond to bid-cover shocks and not the opposite way around. Finally, as discussed in Section 1.2, bid-cover ratios are not manipulation proof. To address the first two concerns, we use month-end observations of OIS-Treasury spreads and all control variables and combine them with the last observed auction result in the same month. As discussed in Section 1.2, the average time between the last auction and the last trading day of the month is ranges from 2.55 days for bills to 20.61 days for notes, ensuring a lag between the bid-cover ratio and the change in

OIS-Treasury spreads. To address the potential shortcoming of the bid-cover ratio, we use the allocations to primary dealers and foreign investors as two alternative demand measures.

Panel (1) of Table 5 shows that using month-end observations leaves the economic significance of the bid-cover ratio almost unchanged – β^{BC} is equal to 7.91 and the R^2 of the regression increases from 4% to 7% after adding bid-cover shocks to the regression. The only difference in control variables compared to Table 4 is that we add the fraction of Treasuries owned by the FED. FED Treasury holdings are statistically significant and an increase of 1% in the FED's Treasury holdings corresponds approximately to a 100 basis point increase in the OIS-Treasury spread. Panels (2) and (3) show the results of using changes in the allocation to primary dealers or to foreign investors as demand proxy. In line with the intuition that a higher allocation to primary dealers is a sign for weakening demand, an increase in primary dealer allocation by 1% corresponds to a decrease of -3.80 basis points in OIS-Treasury spreads (t-statistic 2.54). By contrast an increases in the allocation to foreign investors by 1% corresponds to a 7.54 basis point increase in OIS-Treasury spreads (t-statistic 4.56).

3.3 Two-Stage Least Squares

We now use the negative link between the U.S. Dollar and foreign Treasury holdings in a two-stage least squares setting. In a first stage we regress our demand proxies from month t on changes in the U.S. dollar in month $t-1$, allowing for a different coefficient for Treasury note demand proxies. To improve the power of our instruments, we add the interest rate differential between U.S. Libor (swap) rates IBOR (swap) rates in the G10 currencies.[8] These rate differentials are available for different maturities and a higher USD interest rate

[8]The other G10 currencies are: Euro, British pound, Japanese yen, Australian dollar, New Zealand dollar, Canadian dollar, Swiss franc, Norwegian krone, and Swedish krona. We follow Du et al. (2018) and also add the Danish kornar to these currencies.

Table 5: **Alternative demand measures.** This table shows the regressions of monthly month-end changes in OIS-Treasury spreads with maturities between 3 months and 5 years on the indicated variables. The auction-based demand measures are sampled on the auction date, thereby lagged for several days. $\log(\frac{Outst}{GDP})$ is the ratio of bills (for maturities between 3 months and 1 year) or notes (for maturities between 2 and 5 years) to GDP. $\Delta\frac{FED}{Outst}$ is the share of Treasuries held by the FED. $\Delta OIS1m$ and $\Delta FF - R$ are the change in the short rate and the change in the EFFR-Repo spread respectively. Under 2 SLS, we run a two-stage least squares regression in which we instrument the demand proxies with changes in the trade-weighted dollar index, allowing for a different coefficient for bills and notes, and changes in the equally-weighted interest rate differential between USD Libor rates and Libor rates in the G10 currencies. The numbers in parantheses are heteroskedasticity robust t-statistics. ***, **, and * indicate significance at a 1%, 5%, and 10% level respectively. The sample period is July 2009 to September 2018. Under p weak, we report the p-value of a weak-instrument test.

	OLS			2 SLS		
	(1)	(2)	(3)	(4)	(5)	(6)
Intercept	−0.18	−0.16	−0.14	−0.26	−0.20	−0.17
	(−0.57)	(−0.49)	(−0.45)	(−0.66)	(−0.57)	(−0.46)
BC^s	7.89***			34.96*		
	(3.87)			(1.68)		
Δ PD (%)		−3.80**			−16.89*	
		(−2.54)			(−1.96)	
Δ Foreign (%)			7.34***			23.96**
			(4.56)			(2.26)
$\Delta\log(\frac{Outst}{GDP})$	−17.02***	−17.78***	−17.03***	−17.24***	−21.51***	−18.19***
	(−3.74)	(−4.00)	(−3.85)	(−3.04)	(−4.52)	(−3.90)
$\Delta\frac{FED}{Outst}$	104.56**	100.75**	101.13**	96.08*	70.68	78.42
	(2.45)	(2.32)	(2.31)	(1.95)	(1.51)	(1.51)
Δ OIS 1m	4.82	3.35	3.64	8.14	2.38	3.96
	(1.04)	(0.70)	(0.77)	(1.52)	(0.44)	(0.80)
ΔFF-R	11.63***	11.17***	11.51***	17.33***	17.59***	17.48***
	(3.47)	(3.19)	(3.42)	(3.76)	(4.10)	(4.42)
R^2 without	0.04	0.04	0.04	-	-	-
Adj. R^2	0.07	0.05	0.07	-	-	-
p weak Instr.	-	-	-	8.81%	0.00%	0.00%
Num. obs.	645	645	645	639	639	639

compared to the interest rate in other liquid currencies, makes foreign Treasury investments more attractive. Hence, the U.S. dollar and the U.S. interest rate differential impact foreign demand for Treasuries which, in turn, affect the primary dealer share and the bid-cover ratio.

We argue that the exclusion restriction is satisfied because both lagged changes in the dollar index and lagged changes in the interest rate differential are unlikely to have a direct impact on the OIS-Treasury spread or the Treasury supply. Moreover, the p-value of a weak instrument test ranges from 8.81% for the bid-cover ratio to 0.00% for both primary dealer and foreign allocations, suggesting that we can reject the weak instrument hypothesis. Note that the instruments have a direct impact on foreign allocations and only an indirect impact on the other demand measures. We therefore view the two-stage least squares regression using foreign allocations as our main test.

In line with this intuition, Panels (4)-(6) of Table 5 reveal that the foreign allocation is the most significant explanatory variable in the two-stage least squares setting. A 1% increase in the foreign auction allocation increases the OIS-Treasury spread by 23.96 basis points (t-statistic of 2.26). Despite, the imperfect correlation between the other demand proxies and the instruments, Panels (4) and (5) confirm that positive bid-cover shocks increase the OIS-Treasury spread while increases in primary dealer allocations lower the OIS-Treasury spreads.

4 Evidence from Germany, Japan, and the U.K.

We now put our findings for U.S. Treasuries into perspective by studying three other safe-haven countries: Germany, Japan and the U.K. We provide an overview of the data and institutional background in Section 4.1 and test the link between OIS-Treasury spreads and Treasury demand proxies in Section 4.2.

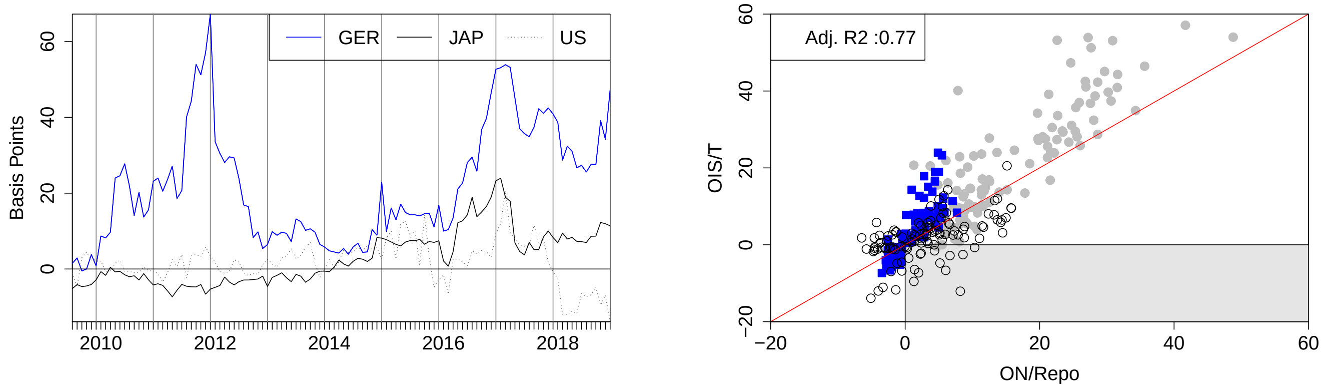
4.1 Data and Institutional Background

The first difference between the U.S. and other countries' Treasuries is that not all benchmark maturities are regularly issued. Table 6 shows summary statistics of Treasury auctions in Germany, Japan, and the U.K. As we can see from the table, Germany and Japan issue 6 month, 1 ,2, and 5-year securities approximately every month. In addition, Japan issues 3-month securities on a weekly basis. The U.K. issues 3-month and 6-month securities on a weekly basis and 5-year securities approximately every month (we ignore the few irregular 2-year and 3-year issuances in our analysis). In contrast to the U.S., Germany uses a discriminatory auction mechanism and approximately 50% of the bids are non-competitive. Hence, it is not surprising that the average bid-cover ratio is lowest for Germany, ranging from 1.59 for 5-year notes to 2.28 for 1-year bills. In contrast, for Japan, where we observe few non-competitive bids, the bid-cover ratio is highest, ranging from 3.81 for 5-year notes to 6.79 for 6-month bills.

Table 6: **Summary statistics for international Treasury auctions.** This table provides summary statistics for different countries and maturities in our July 2009 to September 2018 sample period. # obs is the number of Treasury auctions. $\mathbb{E}[BC]$ and $\sigma(BC)$ are the mean and standard deviation of the bid-cover ratio. $\mathbb{E}[\Delta Days]$ and $\sigma(\Delta Days)$ denote the mean and standard deviation of the days between auctions. For Germany, we also report the percentage of the auction outcomes that are re-openings (as opposed to new issuances).

	Germany				Japan					U.K.		
	6m	1y	2y	5y	3m	6m	1y	2y	5y	3m	6m	5y
#obs	106	88	112	96	461	108	108	108	108	466	466	83
$\mathbb{E}[BC]$	1.89	2.28	1.80	1.60	6.65	6.79	6.14	5.37	3.81	3.44	3.24	1.83
$\sigma(BC)$	(0.51)	(0.67)	(0.37)	(0.37)	(4.63)	(4.57)	(3.79)	(2.18)	(0.67)	(1.22)	(0.96)	(0.38)
$\mathbb{E}(\Delta Days)$	32.47	30.17	30.20	34.93	7.14	30.44	30.50	30.42	30.49	7.12	7.12	40.37
$\sigma(\Delta Days)$	(15.07)	(21.86)	(6.03)	(12.44)	(1.91)	(2.61)	(2.32)	(3.53)	(5.20)	(0.92)	(0.92)	(14.09)
% re-open	8.49	14.77	66.07	75.00	-	-	-	-	-	-	-	-

Figure **??** shows the time series of OIS-Treasury spreads for maturities with regular issuance. We use traded benchmark bond yields where possible. That is, for all countries and maturities except for 3 and 6 month rates in Japan and the U.K. where we regularly observe missing observations – we use Bloomberg's fitted yield curves in these cases. The overnight rate for Germany and the U.K. are the European Overnight Index Average (Eonia) and the Sterling Overnight Index Average (SONIA), respectively. The repo rate for Germany is an index of repo rates with German government bond collateral traded on either the BrokerTec or the MTS electronic platforms. Similarly, the repo rate for the U.K. is an index of repo rates against gilts that trade on BrokerTec. For Japan the repo rate is the JSDA Tokyo overnight repo fixing (an index of reported repo rates) and the uncollateralized rate is the average overnight call rate. As before, we mark the weekly average of the Repo spread with a red-shaded area. The figure shows that OIS-Treasury spreads for Germany are hardly ever negative, while they were negative in Japan in the early part of the sample period and are always negative for 5-year OIS-Treasury spreads in the U.K.



(a) OIS/T

(b) Link to repo

Figure 5: **OIS-Treasury spreads across countries.** Panel (a) shows the time series of the spread between 6-month OIS rates and 6-month government bill yields in Germany, the U.S., Japan. Panel (b) shows a scatter plot of the OIS-Treasury spreads against the spread between the benchmark rate in the underlying OIS and the overnight repo rate. The spreads for Germany, the U.S., and Japan are grey solid dots, black circles, and blue squares, respectively. The sample period is July 2009 to December 2018.

We highlight several key events for the respective countries. For Germany, we mark the Greek downgrade in 2010 (which can be seen as the starting point of the European debt crisis) and Mario Draghi's famous "we do whatever we can" speech in 2012 (which can be seen as the end of the debt crisis). As we can see, OIS-Treasury spreads spike during this period of uncertainty. On 9 March 2015 the Eurosystem started to buy government bonds under the public sector purchase programme (PSPP) and German OIS-Treasury spreads increased after that. The two events highlighted for Japan are the Fukushima tsunami in April 2011 and the Apr 4, 2013 announcement from the Bank of Japan of a new quantitative easing program with sovereign bond purchases As we can see from the figure, Japanese OIS-Treasury spreads are comparably small and became positive in late 2013. Note that the negative sign of the OIS-Treasury spread in the earlier part of the sample period coincided with negative repo spreads. Finally, the picture for the U.K. is mixed with no obvious association between OIS-Treasury spreads and repo spreads. While spreads in the short end are mostly positive, the 5-year spreads are almost always negative. The two events highlighted in the graph are the Oct 6, 2011 announcement from the bank of England that it would run another round of quantitative easing and the date of the Brexit vote on June 23, 2016.

One major factor that could impact differences in OIS-Treasury spreads across countries are the central bank government bond holdings. To get a better idea of the quantitative easing (QE) programs in the different countries, we construct the volume of all trade-able bills and non-bills in these countries, using data from Bloomberg, and compute the ratio of central bank Treasury holdings to Treasuries outstanding. Figure 6 shows that, despite starting later, the ECB bond purchases overtook central bank holdings in other regions. The ECB is followed by the Japanese central bank, which started a massive QE program in 2013, and the bank of England.

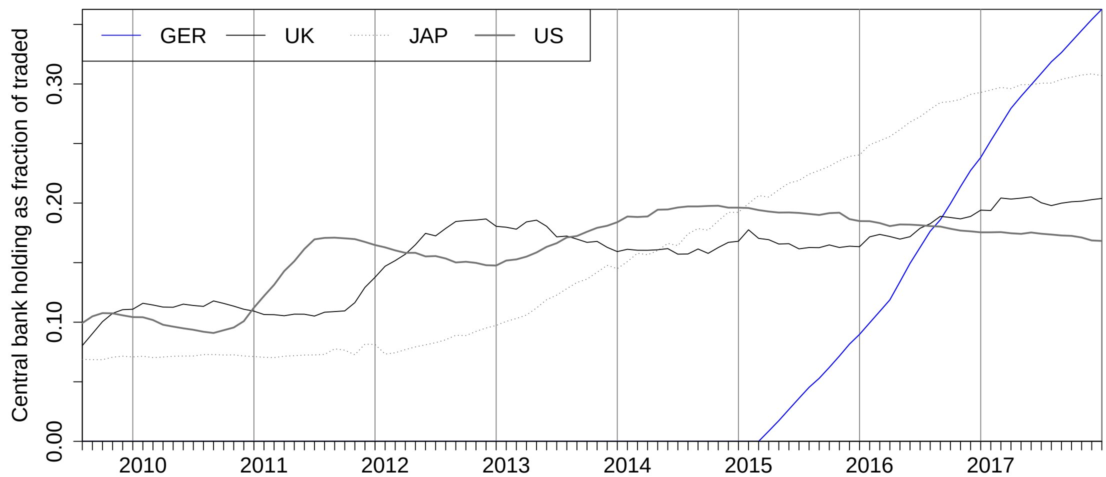


Figure 6: **Share of Treasuries held by central banks in different countries.** This figure shows central bank Treasury holdings in Germany, Japan, the U.K. and the U.S. All ratios are relative to traded public debt.

4.2 Regression Analysis

We now test whether demand and supply effects have a similar impact on OIS-Treasury spreads in Germany, Japan, and the U.K. We proceed similar to our study for the U.S. and regress monthly changes in OIS-Treasury spreads on bid-cover shocks (effectively lagged by several days). In contrast to the U.S. we do not observe an auction outcome every month. We overcome this problem by setting bid-cover shocks equal to zero in months without auctions (our results are robust to considering changes from one auction month to another). As for the U.S., we control for changes in the outstanding-to-GDP ratio, measured as bills-to-GDP for maturities of 1 year and less and as notes-to-GDP for longer maturities.[9] The three other

[9]We define bills as non-coupon-bearing securities with 1 year or less to maturity at issuance and notes as coupon-bearing bullet bonds with less than 10 years to maturity. We download the details on every government bond that was outstanding in our sample period from Bloomberg to construct the outstanding debt volume. Quarterly GDP data are obtained from the IMF.

controls are changes in the fraction of Treasury securities held by the central bank, changes in the short rate, and changes in the overnight-repo spread. Our sample period is July 2009 to August 2018, resulting in 107 months. The number of observations differs across countries different countries issue different benchmark securities.

Panels (1)-(3) of Table 7 show the results of the panel regressions. Bid-Cover shocks are significant explanatory variables for OIS-Treasury spreads in Germany and in Japan, but insignificant in the U.K. In contrast to the U.S., supply proxies do not have any explanatory power. In line with the U.S., central bank government bond holdings are significant explanatory variables for Japan and the U.K. and the overnight-repo spreads are highly significant for all three countries. The additional explanatory power of bid-cover shocks is most visible for Germany, where adding bid-cover shocks increases the R^2 from 0.03 to 0.05.

Table 7: **International OIS-Treasury spreads and demand proxies.** This table shows regressions of monthly month-end changes OIS Treasury spreads on the indicated variables. BC^s is the shock to the bid-cover ratio, sampled on the auction date, thereby lagged by several days. $\log(\frac{Outst}{GDP})$ is the ratio of bills (for maturities between 3 months and 1 year) or notes (for maturities between 2 and 5 years) to GDP. $\Delta\frac{CB}{Outst}$ is the share of Treasuries held by the FED. $\Delta OIS1m$ and $\Delta RepoSprd$ are the change in the short rate and the change in the uncollateralized-collaterized overnight rate spread spread, respectively. Specifications 1–3 include maturity-fixed effects. The numbers in parantheses are heteroskedasticity robust t-statistics. ***, **, and * indicate significance at a 1%, 5%, and 10% level respectively. The sample period is July 2009 to August 2018.

	Panel Data			6-month Spreads			
	GER	JAP	UK	GER	JAP	UK	US
Intercept	0.03	0.05	−0.05	0.02	−0.03	−0.09	0.16
	(0.06)	(0.19)	(−0.10)	(0.03)	(−0.17)	(−0.17)	(0.42)
BC^{shock}	3.54***	0.76**	0.92	6.45***	1.25*	1.15	11.97**
	(2.81)	(1.97)	(0.83)	(2.80)	(1.98)	(0.75)	(2.03)
$\Delta\log(\frac{Outst}{GDP})$	−1.51	6.69	−16.01**	−3.62	8.33	−8.71	−19.81**
	(−0.43)	(1.38)	(−2.07)	(−0.84)	(1.08)	(−0.82)	(−2.16)
$\Delta\frac{CB}{Outst}$	71.81	69.59**	302.72***	80.68	80.10	315.70**	−58.37
	(1.28)	(2.28)	(2.92)	(0.84)	(1.35)	(2.23)	(−0.65)
Δ Rate 1m	−0.60	32.23***	12.83**	1.72	27.29	22.58**	−8.00
	(−0.17)	(2.87)	(2.14)	(0.35)	(0.98)	(2.15)	(−0.69)
Δ Repo Sprd	4.44***	20.76***	14.46***	5.16*	28.07*	23.23***	11.18
	(3.26)	(2.73)	(3.66)	(1.86)	(1.67)	(4.81)	(1.35)
R^2 without	0.03	0.08	0.07	0.03	0.12	0.18	0.05
Adj. R^2	0.05	0.08	0.06	0.11	0.13	0.18	0.11
Num. obs.	440	538	330	110	108	110	110

One potential shortcoming of this analysis is that the samples differ for different countries. We therefore repeat our analysis for 6-month OIS-Treasury spreads, which are the only benchmark maturity available for all four countries. Using only one specific maturity leads to a smaller sample and we lose statistical power. This fact leads to several of the control variables losing their significance. However, most importantly, the demand proxies retain their significance. Coefficient is 12.32 for U.S. followed by 6.48 for Germany and 1.25 for

Japan (insignificant but with the right sign for U.K.). Apart from the U.K., adding the bid-cover shocks improves the explanatory power of all regressions.

5 Alternative Explanations and Demand Measures

In this section, we test our demand-based explanation against various alternative explanations. In Section 5.1 we investigate the potential impact of U.S. credit risk and show the robustness of our results to adding other control variables in Appendix C. We then construct an alternative measure for Treasury demand based on primary dealer holdings and test its link to OIS-Treasury spreads in Section 5.2.

5.1 Debt Ceiling and Credit Risk

Testing for credit risk in U.S. Treasuries is difficult because Credit Default Swap (CDS) premiums for safe countries are not liquid and Klingler and Lando (2018) document that these premiums are more affected by funding frictions than by possible default risk. Despite this shortcoming, we now test whether changes in CDS premiums explain changes in OIS-Treasury spreads, regressing changes in OIS-Treasury spreads (sampled weekly for the Jul 2009 – Sep 2018 sample period) on the corresponding U.S. CDS premium. We use the 6-month CDS premium for the 3-month OIS Treasury spreads and CDS premiums with the same maturity for all other maturities. The first three columns of Table 8 suggest a strong link between OIS-Treasury spreads and CDS premiums for Treasury bills.

Table 8: **Link between OIS-Treasury spreads and CDS Premiums.** This table shows regressions of weekly changes in OIS-Treasury spreads on weekly changes in U.S. CDS premiums. The sample comprises OIS-Treasury spreads with 3 and 6 months, as well as 1, 2, 3, and 5 years to maturity. Except for 3-month OIS Treasury spreads where we pair CDS premiums with 6 months to maturity with and the OIS-Treasury spread, we use CDS premiums with the same maturity as the OIS-Treasury spread. $\mathbb{1}_{DebtCeil}$ is a dummy variable that is equal to one from four weeks before the the resolution of the first and second debt ceiling on August 3, 2011 and October 16, 2013 to one week after the resolution. The sample period is July 2009 – September 2018. All specifications include maturity-fixed effects. Heteroscedasticity robust t-statistics are reported in parenthesis. ***, **, and * denote significance at a 1%, 5%, and 10% level, respectively.

	All	Bills	Notes	All	Bills	Notes
Intercept	−0.03	0.03	−0.09	−0.02	0.04	−0.08
	(−0.74)	(0.52)	(−1.45)	(−0.55)	(0.61)	(−1.28)
CDS	−0.04***	−0.06***	0.00	0.00	−0.03*	0.04
	(−3.35)	(−4.79)	(0.15)	(0.26)	(−1.74)	(1.54)
CDS $\times\mathbb{1}_{DebtCeil}$				−0.09***	−0.05**	−0.16***
				(−4.34)	(−2.38)	(−4.41)
Adj. R^2	0.00	0.01	-0.00	0.01	0.02	0.01
Num. obs.	2724	1338	1386	2724	1338	1386

We next investigate if this association between OIS-Treasury spreads and CDS premiums is linked to the possibility of a technical default of the U.S. As discussed in Section 1, two debt ceiling episodes in 2011 and 2013 brought the U.S. close to a possible technical default on its debt. However, Figure 1 shows only a small drop in OIS-Treasury spreads around the two debt ceiling crisis episodes. In the last three columns we add a dummy-slope variable that is equal to changes in the CDS premium from one month before the projected debt ceiling deadline to one week after the deadline. As we can see from these columns, CDS premiums become insignificant outside of these two debt ceiling episodes (which correspond to 10 observations per maturity segment). Overall, the results suggest that credit risk is of second-order importance in explaining negative OIS-Treasury spreads. We confirm the robustness of our Treasury demand proxies to controlling for credit risk and other factors in Appendix C.

5.2 Link to Primary Dealer Holdings

After motivating our alternative measure for Treasury demand in Section 5.2.1, we test its association with Treasury yield spreads in Section 5.2.2.

5.2.1 Background

A higher auction allocation to primary dealers suggests a weakening demand for Treasuries. We now test if this logic transcends to higher primary dealer Treasury holdings as well.

The New York FED publishes weekly aggregate primary dealer holdings for Treasury bills, non-bills with less than 3 years to maturity, and non-bills with maturity between 3-6 years. We calculate the exact outstanding amounts of Treasury securities in each of the three maturity segments and define our alternative demand proxy – henceforth "relative dealer holdings" – as the ratio between primary dealer Treasury holdings and Treasuries outstanding.

Table 9 shows summary statistics of relative primary dealer holdings. As we can see from the table, the average relative primary dealer holdings are positive and range from 1.21% for Treasury bills to 0.15% for non-bills with less than 6 and more than years to maturity. The last five columns of Table 9 shows that the fraction of Treasuries held by primary dealers increases as the amount of Treasuries outstanding increases, suggesting that primary dealers absorb any excess Treasury supply. Moreover, despite the imperfect timing (primary dealer holdings are published every Thursday, while note auctions are less frequent), a higher dealer allocation in the current auction increases the primary dealer share and the lagged dealer allocation lowers the primary dealer share. This is in line with the notion that dealers are not buy-and-hold investors but sell the purchased Treasuries after the auction.

Table 9: **Descriptive statistics for primary dealer Treasury holdings.** This table provides summary statistics of primary dealer Treasury holdings for three categories: bills, non-bills with less than 3 years to maturity, and non-bills with maturity between 6 and 3 years. The sample period is July 2009 to September 2018. Under *Summary*, the number of observations and the average Primary dealer holdings as a fraction of the total amount outstanding in that category are reported. Under *Regression of* ΔPD, we report the coefficients of regressing changes in the relative primary dealer holdings on precentage changes in outstanding amounts in the relevant category and and the level of aggregate primary dealer auction allocations in the relevant week as well as the lagged allocation. The numbers in parantheses are heteroskedasticity-robust standard errors.

	Summary		Regression of ΔPD				
	# Obs	Mean (SD)	Intercept	$\Delta Outst(\%)_t$	% PD_t	% PD_{t-1}	R^2
Bills	476	1.21	-0.05	0.08	2.35	-2.27	0.10
		(0.72)	(0.21)	(0.02)	(0.41)	(0.39)	
$< 3y$	474	0.39	-0.08	0.05	0.31	0.00	0.20
		(0.75)	(0.02)	(0.02)	(0.06)	(0.05)	
$[3y, 6y)$	469	0.15	-0.03	0.12	0.13	-0.08	0.32
		(0.57)	(0.01)	(0.01)	(0.06)	(0.07)	

Overall, changes in the primary dealer holdings are an alternative indicator of Treasury demand. The advantage of relative primary dealer holdings over auction-based measures is that they are available on a regular weekly basis, making them a valuable alternative demand proxy for Treasury notes. The drawback of primary dealers' Treasury holdings is that they can also be affected by other primary dealer activities, such as interest rate swap hedging or yield curve arbitrage. Nevertheless, Table 9 suggests that one major driver of relative dealer holdings is their activity in the primary market.

5.2.2 Results

Our analysis of relative primary dealer holdings is similar to the previous analysis for bid-cover shocks presented in Table 4. The main differences are that we now use use weekly changes in all indicated variables and drop the test with time-fixed effects. The results of the new test are shown in Table 10.

Starting with panel (1), we can see that primary dealer holdings are a significant explanatory variable for OIS-Treasury spreads and an increase in primary dealer Treasury holdings by 1 percent corresponds to a decrease of -0.54 basis points in OIS-Treasury spreads. Splitting the sample into bills and notes reveals several differences compared to the analysis in Table 4. First, changes in primary dealer holdings are only borderline significant for Treasury bills while bills-to-GDP are more significant. Hence, primary dealer bill holdings are an imperfect proxy for the short end. This is not surprising given that we only observe aggregate holdings across all bills. By contrast, the statistical and economical significance of relative primary dealer holdings increases for Treasury notes. Here, a one percent increase in primary dealer Treasury holdings corresponds to a 1.85 basis point decrease in OIS-Treasury spreads. Moreover, half of the 6% R^2 of this regression comes from changes in relative primary dealer holdings.

As before, we repeat the analysis for alternative yield spreads. The results are qualitatively similar but weaker for both Libor-Treasury and Off-the-run on-the-run spreads. Comparing next the effect of relative primary dealer holdings on raw changes in Treasury yields and OIS rates shows that changes in relative dealer holdings only affect Treasury yields, while OIS rates are unaffected.

Table 10: **Link between Treasury yields and dealer holdings.** This table shows the results of various regressions of Treasury yield spreads on changes in primary dealer Treasury holdings, controlling for the FED Treasury holdings, the ratio of bills-to-GDP or notes-to-GDP, changes in the 1-months OIS rate, and changes in the spread between EFFR and repo rate. In panels (1)-(3) the dependent variable is the OIS-Tresaury spread, utilizing our full sample of OIS-Treasury spreads with maturities between 3 months and 5 years, the sub-sample of Treasury bills, and the sub-sample of Treasury notes, respectively. The dependent variable in Panel (4) is the Libor-Treasury spread, measured as Libor rate minus Treasury yield for maturities up to one year, and as swap rate minus Treasury yield for longer maturities. The dependent variable in Panel (5) is the on-the-run off-the run spread. In Panels (6) and (7) we analyze changes in the Treasury yields and changes in the OIS rates, respectiverly. All specifications include maturity-fixed effects. The numbers in parantheses are heteroskedasticity robust t-statistics. ***, **, and * indicate significance at a 1%, 5%, and 10% level respectively. The sample period is July 2009 to September 2018.

	OIS/T Spreads			Other Measures			
	(1) All	(2) Bills	(3) Notes	(4) Lib/T	(5) Off/On	(6) UST	(7) OIS
Intercept	-0.01	-0.02	-0.10	-0.02	-0.03	0.12	0.11
	(-0.06)	(-0.14)	(-1.00)	(-0.14)	(-0.30)	(0.77)	(0.86)
$\Delta \frac{Hold}{Outst}$	-0.55^{***}	-0.26^{***}	-1.85^{***}	-0.43^{***}	-0.59^{***}	0.43^{**}	-0.10
	(-5.15)	(-2.62)	(-5.15)	(-3.52)	(-4.22)	(2.51)	(-0.67)
$\Delta \log(\frac{Outst}{GDP})$	-2.03	-11.79^{***}	61.39^{***}	-0.79	2.47	-1.94	-4.65
	(-0.45)	(-2.75)	(3.62)	(-0.15)	(0.41)	(-0.26)	(-0.73)
$\Delta \frac{FED}{Outst}$	26.56^{**}	8.12	32.12	36.27^{**}	43.15^{**}	-19.09	6.34
	(2.00)	(0.50)	(1.49)	(2.09)	(2.49)	(-0.77)	(0.29)
Δ OIS 1m	-6.59^{*}	-4.55	-5.60	-5.54	2.33	76.06^{***}	69.84^{***}
	(-1.93)	(-0.83)	(-1.38)	(-1.18)	(0.60)	(10.93)	(11.16)
ΔFF-R	1.67	3.74^{*}	2.51	3.51^{*}			
	(0.91)	(1.70)	(0.83)	(1.75)			
R^2 without	0	0.01	0.03	0	0	0.04	0.04
Adj. R^2	0.01	0.01	0.06	0.01	0.01	0.04	0.04
Num. obs.	2779	1395	1384	2775	2779	2779	2779

6 Conclusion

We show that in the aftermath of the financial crisis, U.S. Treasury yields have frequently exceeded the risk-free rates as proxied by the fixed rate in the overnight indexed swap rate with matching maturity. These negative OIS-Treasury spreads arise from the cheapening of the U.S. Treasury, due to a drop in the demand. We construct several proxies for the demand for sovereign debt from the primary auctions of sovereign debt, including the bid-cover ratios, primary dealer holdings, and the auction awards to foreign investors. All these demand proxies play an important role in explaining the spreads between sovereign debt yields and the OIS rates. While adverse demand shocks cause all sovereign debt yields to fall, we show that U.S.Treasury yields have lost their convenience yields, while German sovereign yields continue to enjoy signifiant convenience yields.

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A Data Description

1. *OIS-Treasury spreads:* For the U.S., we obtain OIS rates from the Bloomberg system and use constant maturity Treasury (CMT) yields from the FED H.15 reports. The daycount convention for OIS with more than one year to maturity is actual/360 while all other daycount conventions are actual/actual. We take these differences into account when computing the spreads. For Germany, Japan, and the U.K. we obtain OIS rates and benchmark bond yields from the Bloomberg system. Due to missing observations, we use Bloomberg yield curve data for 3 and 6 months government bond yields in Japan and the U.K.
2. *On-the-run spread:* The off-the-run Treasury yields are constructed as explained in Gürkaynak, Sack, and Wright (2007) and data are obtained from `http://www.federalreserve.`

gov/pubs/feds/2006. The on-the-run spread is the difference between these off-the-run yields and the CMT Treasury yields described above

3. *Repo rates.* For the U.S., we construct a volume-weighted repo index based on repo volumes from the New York FED wbesite and GCF and triparty repo rates from DTCC and Bank of New York Mellon, respectively. After January 2018 we use secured overnight funding rates (SOFR) are repo rates. Before January 2005 we use overnight repo rates from the Bloomberg system. The repo rate for Germany is obtained from http://www.repofundsrate.com, which calculates a daily repo rate index based on repos with German collateral that traded on either the BrokerTec or the MTS electronic platforms. Similarly, the repo rate for the U.K. is the Sterling Repo Index Rate (obtained from http://www.nexdata.com), a daily index capturing the funding costs against Sterling Government bonds that trade and clear on BrokerTec. For Japan, we use the JSDA Tokyo overnight repo fixing from http://www.jsda.or.jp/en. This is an index of repo rates against Japanese government bonds, currently reported by 14 major Japanese banks

4. *Unsecured overnight rates.* We use the unsecured overnight rates that are the basis for the respective OIS. In the U.S., we use the EFFR (obtained from https://fred.stlouisfed.org, ticker: DFF). For Germany and the U.K. we use the EONIA and SONIA rate, respectively. For Japan we use the uncollateralized overnight call. All three variables are obtained from the Bloomberg system.

5. *Libor-Treasury spread.* We obtain Libor rates for maturities up to one year and (Libor) swap rates for maturities with more than one year from the Bloomberg system. We then compute the spread between Libor rates and CMT Treasury yields, taking the different daycount convention for swaps (actual/360) into account.

6. *Auction results.* U.S. bid-cover ratios, auction volumes, and primary dealer allocations are obtained from `www.treasurydirect.gov`. Foreign allocations from the Treasury website (`https://www.treasury.gov/resource-center/data-chart-center/Pages/investor_class_auction.aspx`). Data for Germany, Japan, and the U.K. are obtained from the websites of the respective debt management offices.
7. *Debt-to-GDP Ratio:* For the U.S., we construct debt-to-GDP ratios based on issuance volumes obtained from `www.treasurydirect.gov` and quarterly GDP estimates from `https://fred.stlouisfed.org` (ticker: GDP). For other countries we construct outstanding amounts based on bond issuance volumes, issue and maturity dates from Bloomberg. Quarterly GDP data are obtained from the IMF.
8. *Central bank Treasury holdings.* Volume of official foreign U.S. bill holdings. Obtained from the Treasury website (in million USD). Divided by outstanding volumes constructed based on Treasury direct data. Germany: ECB monthly purchases divided by volume constructed from BB. U.K. ? Japan?
9. *Relative primary Dealer Treasury Holdings.* Primary dealer bill and note holdings are obtained from the NY FED website. We construct the exact amounts of Treasuries outstanding in each of the categories based on data from `www.treasurydirect.gov`.
10. *US Dollar Index:* From FED (major currency index)
11. *Cross-currency basis:* From Bloomberg.
12. *CDS premiums on the U.S. treasury:* The U.S. CDS premiums are 5-year CDS premiums of Euro-denominated CDS contracts (which are the most liquidly traded CDS contracts on the U.S. treasury). The data are obtained from Markit.
13. *OIS Volumes.* From DTCC data warehouse

B The OIS-Treasury Arbitrage

Table 11 gives an overview of the cashflows from the OIS-Treasury arbitrage strategy. The main friction affecting this strategy is the funding of the Treasury long position. To get an idea of the profitability of the strategy, we proceed as follows. Every month, we chack if the OIS-Treasury spread is negative and engage in the positions described in Table 11 if it is. We assume no transaction costs and set the total haircut of the position to 4% (2% repo haricut and 2% initial margin for the OIS). To simplify computations, we assume the average return across all invested positions. For example, for the 2-year spread, every month a total of up to 24 positions is invested in the strategy. If the arbitrageur is currently invested in 7 positions we sum up the returns from these positions and divide by 7 (even if he was invested in 20 positions at the time he invested in the position that pays the carry now). If there are no investments in one month, we ignore that month.

Table 11: **Arbitrage strategy for negative OIS-Treasury spreads.** This table summarizes the cashflows from the negative OIS-Treasury arbitrage. OIS_0 denotes the fixed rate in an OIS with maturity T, ff_t denotes the variable fed funds rate at time t, c_0 denotes the coupon of a treasury bond with maturity T, and r_t denotes repo rate at time t.

	$t=0$	$t=1$	...	$t=T$
Pay fixed rate OIS_0 in OIS	0	$-OIS_0$	...	$-OIS_0$
Receive $EFFR_t$ from OIS	0	$+EFFR_t$	...	$+EFFR_T$
Buy bond with coupon c_0	-1	$+c_0$	...	$+1+c_0$
Borrow at repo rate r_t	$+1$	$-r_t$	...	$-1-r_T$
Payoff	0	$-(OIS_0-c_0)$	...	$-(OIS_0-c_0)$
		$+(ff_t-r_t)$	...	$+(ff_T-r_T)$

To compute the carry from the strategy we make the simplifying assumption that any semi-annual Treasury coupon payments are held in cash, such that the interest payments of the OIS and Treasury occur at the same time. We further assume that the Treasury pays the yield (not the coupon) and that the maturity dates match exactly (this assumption is reasonable given the monthly issuance of new Treasury securities). The cashflows from the floating leg of the OIS are computed as:

$$\prod_i [\left(1+\frac{d_i}{360} r_t\right) - 1]\frac{360}{D}, \tag{2}$$

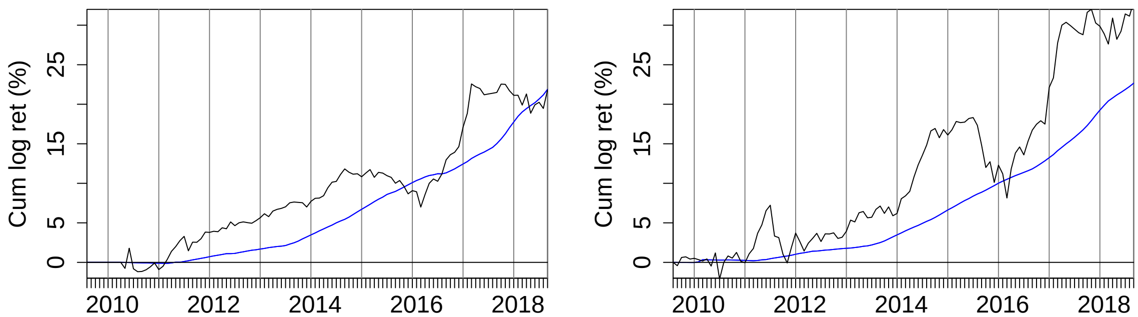
where i goes through all business days in reference period, r_i is the EFFR for business day i, d_i is the number of calendar days to which r_i applies, and $D = \sum_i d_i$.[10] We use the same formula to compute the financing costs for the fixed lag, using the repo index described in Section 1.

To get an idea of the riskiness of the position, we also use marking to market (MtM), obtaining the term structure of OIS and Treasuries up to 5 years from Bloomberg and from the FED respectively (note that all contracts up to 1 year are zero-coupon). We then interpolate par Treasury yields to obtain 1.5, 2.5, 3.5, 4, and 4.5 year yields. This step is only necessary for 4 year OIS because of their annual coupon payments. We then bootstrap the zero-coupon curves (straight-forward procedure because we have as many rates as we have payments) and interpolate to obtain discount factors on each Treasury and OIS valuation date. Every month, we then calculate the value of the OIS and Treasury positions using their respective yield curves. We also assume that there is no penalty for drawdowns.

Returns

Figure 7 illustrates the cumulative excess returns from the strategy, using only 2-year OIS and Treasuries (panel (a)) and using all available maturities (panel (b)).

[10]The cashflows of the OIS are paid annually and hence, for contracts with one year or less time to maturity, the only payment occurs at the maturity of the contract.



(a) 2-year OIS/Treasury

(b) Average OIS/Treasury

Figure 7: **Returns from OIS-Treasury arbitrage.** This graph shows the cumulated logarithmic returns from engaging in the OIS-Treasury arbitrage strategy. The blue line shows the cumulated carry from the strategy in excess of the risk-free rate and the black line shows the returns when each position is marked to market. In the first panel we show the returns from the 2-year OIS-Treasury arbitrage and in the second panel the average returns across all six maturities.

Table 11 provides summary statistics of the near-arbitrage returns for different maturities. As we can see from the table, it is possible to earn statistically significant returns for maturities of one year and above.

Table 12: **Returns from OIS-Treasury Arbitrage.** This table presents summary statistics of the returns from engaging in the OIS-Treasury arbitrage. Return is the sum of carry and mark-to-market returns, min(Ret) and max(Ret) are the minimum and maximum returns in our July 2009 – September 2018 sample period. SR (%) is the sharpe ratio of from the strategy and Avg carry the average carry.

	3 m	6 m	1 yr	2 yr	3 yr	5 yr	Avg
Return	0	0.02	0.1	0.2	0.23	0.46	0.31
(t-stat)	(-0.61)	(0.9)	(2.18)	(2.25)	(1.87)	(1.88)	(2.19)
min(Ret)	-0.39	-0.77	-2.2	-2.57	-6.24	-9.58	-3.83
max(Ret)	0.34	1.08	2.45	3.81	3.96	7.31	4.75
SR (%)	-6.5	8.7	19	22.6	16.9	16	20.9
Avg Carry	-0.01	0.03	0.15	0.2	0.19	0.23	0.21

C Robustness to Other controls

This section contains various additional robustness checks. Comparing Panels (1) and (2) of Table 13 shows that our findings are robust to using changes in the bid-cover as demand proxy. In Panel (3), we add time-fixed effects to the regression, which leaves the statistical and economic significance of bid-cover shocks in tact. In Panel (4), we add the implied volatility of the S&P 500 (a common proxy for safety demand) and primary dealer constraints as explanatory variables. As we can see from the table, adding these variables leaves the coefficient on bid-cover shocks virtually unchanged. In Panel (5), we add changes in the U.S. CDS premium, a version of the Bloom, Baker, and Davis (2012) economic policy uncertainty index that captures concerns about the U.S. debt ceiling, and U.S. recession probabilities as controls. These variables add explanatory power to our regressions and have the expected sign (increases in CDS premiums or recession probabilities should increase Treasury yield spreads). However, the coefficient on bid-cover shocks remains virtually unchanged. Finally, Panel (6) shows that any combination of control variables leaves the coefficient on bid-cover shocks virtually unchanged.

Table 13: **Robustness to additional controls.** This table shows regressions of monthly month-end changes in OIS-Treasury spreads with maturities between 3 months and 5 years on the indicated variables. The auction-based demand measures are sampled on the auction date, thereby lagged for several days. ΔBC is the change in bid-cover ratio from one auction date to the next. $\log(\frac{Outst}{GDP})$ is the ratio of bills (for maturities between 3 months and 1 year) or notes (for maturities between 2 and 5 years) to GDP. $\Delta \frac{FED}{Outst}$ is the share of Treasuries held by the FED. $\Delta OIS1m$ and $\Delta FF - R$ are the change in the short rate and the change in the EFFR-Repo spread respectively. PD Constraints is the primary dealer leverage factor from He, Kelly, and Manela (2017). ΔVIX are changes in the implied volatility of the S&P 500. ΔCDS captures changes in the U.S. CDS premium. EPU DebtCeil is the economic policy uncertainty index from Bloom, Bloom, and Davis (2012). Rec prob is the U.S. recession probability. The numbers in parantheses are heteroskedasticity robust t-statistics. ***, **, and * indicate significance at a 1%, 5%, and 10% level respectively. The sample period is July 2009 to September 2018.

	(1)	(2)	(3)	(4)	(5)	(6)
Intercept	-0.23	-0.17	-2.96	-0.07	-1.59^{**}	-1.52^{**}
	(-1.59)	(-0.51)	(-1.14)	(-0.22)	(-2.11)	(-2.05)
ΔBC	2.13^{***}					
	(4.98)					
BC^s		7.86^{***}	7.71^{***}	7.88^{***}	7.73^{***}	7.51^{***}
		(3.84)	(4.18)	(3.74)	(3.84)	(3.72)
$\Delta \log(\frac{Outst}{GDP})$	-17.75^{***}	-16.63^{***}	-20.96^{***}	-17.10^{***}	-19.00^{***}	-20.15^{***}
	(-3.90)	(-3.57)	(-4.16)	(-3.75)	(-4.21)	(-4.42)
Δ OIS 1m	6.45	7.07	-133.80	7.22	8.23	8.71
	(1.37)	(1.51)	(-1.19)	(1.13)	(1.29)	(1.35)
$\Delta \frac{FED}{Outst}$	103.51^{**}	109.18^{**}	-4861.77	96.87^{**}	117.64^{***}	113.64^{**}
	(2.48)	(2.58)	(-1.40)	(2.23)	(2.59)	(2.51)
ΔFF-R	10.98^{***}	11.13^{***}	-131.45	15.63^{***}	16.38^{***}	16.21^{***}
	(3.28)	(3.35)	(-1.60)	(4.72)	(5.52)	(5.47)
PD Constraints				-2.46		-3.92^{**}
				(-1.27)		(-2.04)
ΔVIX				-0.07		-0.08^{*}
				(-1.54)		(-1.79)
ΔCDS					-0.05^{***}	-0.05^{***}
					(-3.92)	(-3.98)
EPU DebtCeil					-0.17^{*}	-0.16^{*}
					(-1.91)	(-1.81)
Rec Prob					-0.07^{**}	-0.07^{**}
					(-2.11)	(-2.36)
Time FE	No	No	Yes	No	No	No
Adj. R^2	0.08	0.06	0.43	0.08	0.11	0.12
Num. obs.	659	659	659	599	587	587