PRELIMINARY

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The Complexity of Liquidity:

The Extraordinary Case of Sovereign Bonds

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Abstract:

It is well-documented that government bonds with almost identical cash flows can trade at different prices. The explanation is that, due to liquidity, the most recently issued bond tends to trade at a premium to more off-the-run bonds. This paper analyzes the cross-section of bond spreads across developed countries over a 15-year time period and documents a startling finding in contrast to this thinking. Not only is liquidity not common across countries, but, under certain conditions, especially related to credit deterioration and flight to quality, bond spreads tighten and *actually go negative*. In other words, the liquid bonds become cheaper, not more expensive, than their less liquid counterparts. We offer an explanation based on temporary price pressure and provide empirical support using data on net flows of investors in sovereign bonds. Of some interest, we are able to reconcile the differential behavior of bond spreads of the U.S. and Germany versus Spain and Italy during the Eurozone crisis period.

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I. Introduction

It is now well documented that there are numerous violations of the law of one price for financial assets, i.e., securities with almost identical cash flows can trade at different prices. There is arguably no better illustration of this phenomenon than that of government bonds, in particular, between the pricing of the most recently issued ("on-the-run") bond and a matched ("off-the-run") counterpart.[1] In particular, the extant literature finds the yield spread between off- and on-the-run bonds (hereby denoted off/on the run spread) to be meaningfully positive and time-varying. The basic story advanced in this literature is liquidity; in other words, because the on-the-run bonds are more able to trade at the prevailing price with immediacy and with little price impact, investors value that feature and pay a higher price for it.

The level and variation of liquidity in the government bond market, however, can arise through a variety of sources, including exogenous transactions costs, demand pressure and inventory risk, and difficulty in locating trading counterparties (see, for example, the survey by Amihud, Mendelson and Pedersen (2005)).[2] One of the questions resulting from this literature is the extent to which these sources are common across government bonds; is the off/on the run spread explained by common liquidity shocks ("flight to liquidity") (e.g., Longstaff (2004) and Goyenko, Subrahmanyam and Ukhov (2011))? A related literature looks at sovereign government bonds of various credit quality and decomposes the sovereign spread into a flight to liquidity and aggregate economy shocks ("flight to quality") (e.g., Beber, Brandt and Kavajecz (2009) and Favero, Pagano and Von Thadden (2010)).

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[1] See, for example, Cornell and Shapiro (1990), Amihud and Mendelson (1991), Warga (1992), Boudoukh and Whitelaw (1993), Kamara (1994), Elton and Green (1998), Jordan, Jorgensen, and Kuipers (2000), Krishnamurthy (2002), Longstaff (2004), Goldreich, Hanke and Nath (2005), Pasquariello and Vega (2009), and Goyenko, Subrahmanyam and Ukhov (2011).

[2] Some specific theories relevant to the liquidity of the government bond market include Amihud and Mendelson (1986), Grossman and Miller (1988), Boudoukh and Whitelaw (1993), Duffie, Garleanu and Pedersen (2002), Vayanos (2004), Vayanos and Weill (2008) and Pasquariello and Vega (2009), Favero, Pagano and Von Thadden (2010), and Banerjee and Graveline (2013).

In this paper, we study the behavior of the off/on the run spread between newly issued and previously issued government bonds across a range of maturities and countries over an extensive time period, 1998 to 2015. By construction, the spread reflects the relative pricing of government bonds that differ only by issuance date and not by credit risk. The behavior of the spread is at times startling and provides a challenge to existing research on liquidity. As some examples:

- From 2009 to 2013, the off/on the run spreads of Italian and Spanish government bonds are consistently negative across all maturities. In other words, the price of the liquid on-the-run bond falls *below* the less liquid off-the-run bonds.
- Across the term structure, the off/on the run spread of some sovereign government bonds, including the U.S., are only marginally correlated. For example, the average correlation between the 10-year and 5-year spreads is 0.15. In other words, on average, there is little commonality in liquidity shocks.

If in fact the on-the-run bonds are more liquid than off-the-run bonds, then how can off/on the spreads turn negative and be barely correlated across maturities? Of course, there exist many time periods when the spreads of all bonds, both across maturity and across countries, are positive and move together. Such cases are related to the default of Russian debt and the so-called LTCM crisis (i.e., the failure and then bailout of the large fixed income hedge fund, Long Term Capital Management) as well as around the bankruptcy of Lehman Brothers in September 2008. Our paper provides a framework for understanding these and other stylized facts.

Under extreme conditions, precisely because on-the-run bonds are easier to transact in, greater price discovery takes place in these bonds. That is, price pressure, whether temporary (through flows) or permanent (through information), can push the price of the on-the-run bond more than the off-the-run bonds (see Greenwood and Vayanos (2010) and D'Amico and King (2013) for evidence of price pressure in on-the-run governments). In these periods of intense pressure, the market for off-the-run governments is segmented and may not reflect the price pressure. The reason is that investors are reluctant to transact in older government bonds, especially on the short side, because these investors may get stuck with the transaction (e.g., Graveline and McBrady (2011) and Banerjee and Graveline (2013)). Prices can therefore diverge in segmented markets with heterogenous investors (e.g., Boudoukh and Whitelaw (1993)).[3] The natural arbitrage here would be to buy the cheaper on-the-run bond and short the more expensive off-the-run bond,

[3] See also Harrison and Kreps (1978), Ofek and Richardson (2003), Hong and Stein (2003) and Geanakoplos (2003).

but this is difficult to implement due to the shorting issue. This is further complicated by the fact that the on-the-run bonds are destined to go off-the-run in the near future (e.g., Goldreich, Hanke and Nath (2005)). Using information about global credit risk ("flight to liquidity"), sovereign credit risk ("flight to quality"), the shape of the yield curve and sovereign government bond flows (as a proxy for investor demand for specific maturities), we are able to infer price pressure episodes and explain the remarkable behavior of the off/on the run spreads.

There are several unique aspects of our analysis. First, we study a 17-year period compared to previous studies on sovereign government bonds (e.g., 2002-2003 in Favero, Pagano and Von Thadden (2010) and 2003-2004 in Beber, Brandt and Kavajecz (2009)). The longer period provides much more power to detect liquidity effects, including the aforementioned LTCM crisis, the 9/11 terrorist attack, the financial crisis and the Euro crisis, among other episodes. Second, because we are comparing the spread of likewise government bonds, credit risk is netted out. The off/on the run spreads therefore cannot reflect differential default rates. Third, the off/on the run spread is usually calculated as the difference between the newly issued bond and the most recently issued bond (e.g., Krishnamurthy (2002) and Pasquiarello and Vega (2009)). One of the problems with this calculation is that the off-the-run bond can have quite different coupon rates and be of a different maturity depending on the issuance cycle. Here, we construct a new measure of the off/on the run spread by estimating the parallel shift in the entire off-the-run zero curve necessary to price the on-the-run bond. We show that this method has preferable qualities to the typical off/on the spread calculations.

The paper presents novel findings for the relative pricing of sovereign government bonds and may imply broader consequences for the pricing of liquidity. First, surprisingly, we document little commonality in liquidity across countries and across the term structure within a country even though the sample contains a number of liquidity and crisis events. Correlations between sovereign bond spreads (and residuals from sovereign bond spread regressions) are often negative and rarely above 20%-30%. Second, while there is evidence in support of the standard liquidity premium (i.e., more recently issued bonds are on average more expensive than likewise bonds), this finding does not explain time variation in the off-the-run versus on-the-run spread. Indeed, we document that, in the very time one might value liquidity (such as flight to quality as represented by net flows or deteriorating liquidity quality), the spreads actually tighten or go negative. Specifically, in a pooled time-series regression of bond spreads on a country's relative credit quality, we document R^2s on the order of 20%. In other words, liquid bonds become cheap (expensive) relative to less liquid bonds when a country's credit condition worsens. We argue and show evidence that this is due to price pressure more readily showing up in the liquid bond. Finally, the behavior of the off-the-run and on-the-run spreads in the cross-section behaves differently for the so-called safe haven countries of United States and Germany versus the other countries. This is true with respect to credit quality, net government bond flows and global liquidity factors. Some of the results provide a challenge to future research.

The paper is organized as follows. In Section II, we describe the data and, in particular, focus on the methodology for comparing recently issued bonds to more off-the-run bonds. Section III documents the main results of the paper, showing that sovereign liquidity spreads actually tighten when the sovereign runs into trouble and suffers a flight to quality. We provide an explanation provide supporting evidence using a dataset of net flows of sovereign government bonds. In section IV, the analysis and arguments are extended to multiple maturities for several available term structures of particular countries. Section V concludes.

II. Data Description

Our primary data source for government bond prices is Data Scope Fixed-Income (DSFI) from Thomas Reuters. We process a total of 3734 treasury bonds and 6809 treasury bills issued by the 13 largest issuers from developed countries: Australia, Belgium, Canada, Denmark, France, Italy, Germany, Japan, Netherlands, Spain, Sweden, UK and US. The dataset starts from 1993 according to Reuters; but the coverage can vary by country. For European countries, DSFI does not contain complete price history for a large number of bonds issued pre-euro. We focus on the data post 1998, with the exception of US where we use the full sample starting from 1993. We use Bloomberg as our secondary data source when DSFI data is either not available or erroneous.

The purpose of this paper is to compare the prices of government bonds which differ only by when they were issued, as a proxy for their liquidity. Unlike the United States, a number of countries do not issue new bonds, but simply reissue existing ones. To identify the on-the-run bonds, we need the last issuance/ reissuance date for each of the candidate bonds. For any given set of sovereign bonds, we keep track of the re-openings of the same security as well as issuances of new securities. We only consider the issuances where the issued amount is more than 70% of the original amount issued when the bond was first auctioned. To determine which tenor a bond belongs to, we compute the remaining time-to-maturity the last time when the bond is issued. We classify a bond with remaining time-to-maturity between 8.5 and 11.5 years (resp. between 4.5 and 6.5 years) to be a 10 year bond (resp. 5 year).

Moreover, in order to classify the on-the-run bond, i.e., the most recently issued bond, we restrict the analysis to country and tenors with regular issuance after 1998. A country/tenor will be included if (i) its earliest issuance is before 1998:01; (ii) there are at least 17 issuances (one bond per year); (iii) the largest gap must not exceed the smaller of 3 years or a quarter of the maturity; and (iv) from 1998 onwards, there is always at least one bond that can be considered to be this country/tenor (e.g., a 15 year bond re-opened when it has 10 year time to maturity is considered a 10 year bond after re-opening).[4] For 11 issuers in the sample (Australia and Denmark aside), we are able to identify a 10-year on-the-run bond, and, for five countries in particular (France, Germany, Italy, Japan and the United States), we can identify other tenors.

Appendix 1A documents properties of the issuance cycle for the 10-year on-the-run bond.[5] The number of on-the-run 10-year bonds range from a low of 19 for Canada and Germany to a high of 144 for Japan. Related, the average issuance cycle is 364 days for German bonds while just 45 days for Japanese bonds. As a frame of reference, the U.S. has 81 new issue 10-year bonds with an average issuance cycle of 104 days.

The goal of this paper is to analyze the spread between likewise sovereign government bonds that differ only by their liquidity. As described in the introduction, there is a considerable literature focused primarily on the United States Treasury bond market that compares the yields of the on-the-run versus the next most recently issued comparable bond. As Appendix 1A shows, other than Japan, the issuance cycle is considerably longer for other country's 10-year bonds. This lengthy cycle makes the comparison problematic. The reason is that if the term structure of interest rates is not flat, then the difference in maturity may be significant enough to obscure the liquidity premium inherent in the yield spread between the on-the-run and off-the-run bond. Table 1A documents the properties of the yield spread country by country.

To the above point, for all the countries, except the U.S., the average spread is actually negative. If the term structure is upward sloping over this period, and there is a sufficient gap in the

[4] The only exception is UK – none of the tenors qualify as "regular issuance". We use the UK 10 year to represent UK.
[5] Appendix 1B provides similar information for the other tenors. These bonds will be analyzed and discussed in Section IV of the paper.

issuance cycle, then there will be a bias towards a negative spread. In order to understand how important the bias is, note that the yield difference between on-the-run and 1st off-the-run is a combination of local slope of the yield curve and the liquidity premium of the on-the-run (or illiquidity discount of the off-the-run). To illustrate this point, we use off-the-run curve to price the on-the-run bond and compute its hypothetical yield if it were priced by the curve accurately. We construct the local slope measure as 1st off-the-run yield minus the hypothetical on-the-run yield.

Table 1B reports regressions of the off- minus on-the-run yield spread on this local measure of the term structure slope, as well as estimates of duration and convexity. The coefficient on the term structure slope is 0.88 and explains an astonishing 76% of the variation of the yield spread. Country fixed effects add just a fraction to the explained variation. Table 1B shows that the yield spread is related to the difference of duration and convexity. However, conditional on local slope, the relationship disappears. This reassures the thesis that a large part of the yield spread is explained by the slope of the term structure and cash-flow difference between the two bonds.

The results of Table 1 suggest that, outside of the United States, any analysis of the spread between on-the-run and the most recent off-the-run issue will be difficult in light of the importance of the coupon and maturity mismatch. This is a well-known issue in trying to match bonds of different liquidity. (See Fleming (2001), Longstaff (2004) and Schwartz (2010).) For example, Longstaff (2004) compares Refcorp and Treasury bonds in the U.S. as a way to isolate liquidity because neither bond issues have credit risk. To adjust for the maturity mismatch, he creates constant maturity yields based on constructed zero curves from Refcorp and Treasury bonds across available maturities. The yield spread thus is relatively insensitive to term structure characteristics. We follow a similar strategy here.

In particular, we pool together all the applicable off-the-run bonds of a given country. We then bootstrap a zero curve using only these off-the-run bonds. We compute a hypothetical price for each of the on-the-run bonds assuming these bonds are priced by the same zero curve, discount factors. The spread between the off-the-run hypothetical bond and the on-the-run bond, denote OTR-spread, is defined as the shift in the zero curve that would price the bonds equally. Mathematically, $OTR - spread = y^{hyp} - y^{actual} = \frac{price^{hyp} - price^{actual}}{price^{hyp} \cdot duration}$. We use the adjusted Fisher-Weil duration to capture the price sensitivity to the parallel shift of the yield curve. Intuitively, the OTR spread has the interpretation of the number of basis points yield curve has to shift down so that the on the run bond can be priced by the curve.

Table 2 documents the properties of the OTR-spread of the 10-year bond country by country. In contrast to the results of Table 1A, Table 2A documents that the spread is on average positive for all countries except Japan and Italy. The positive spread is consistent with a premium for holding off-the-run bond issues compared to the most recently issued on-the-run bond. The range of average spreads varies from a low of -2.6 basis points for Italy to a high of 3.8 basis points for Canada. It is worth commenting on two other features of the OTR-spread. The first is that the OTR-spread has considerable variation over the time period, with volatilities on the order of several basis points, and extremes ranging from both negative to positive spreads. The second is that the OTR-spreads are persistent, dying out slowly over a number of months. For example, on average, the autocorrelations at 1-week, 1-mth, 3-mth, and 6-mths are respectively 0.88, 0.69, 0.47 and 0.35.

Table 2B reports an analogous analysis to that of Table 1B by regressing the OTR-spreads on our local measure of the term structure slope, as well as estimates of duration and convexity. The coefficient on the term structure slope is now -0.08 and, net of country fixed effects, explains only 2% of the variation of the OTR-spread. Country fixed effects now add approximately 13% to the variation, suggesting that there are built-in-differences of the liquidity premium across countries. Duration and convexity measures alone do not add much to the explained variation of OTR-spreads though these measures come in significant, especially with fixed effects. In contrast to the results of Table 1B, our conclusion is that the OTR-spread is not explained by the slope of the term structure which is to be expected given the OTR-spread, by construction, matches maturity and cash flows.

As a comparison between the OTR-spread and the more standard off- minus on-the-run spread, Figures 1A-1K graph the two spreads over the time period for all eleven countries. The slope between the 10-year and 2-year bonds is also provided for each country. The slope is labelled on the right-hand side of the figure whereas the spreads are labeled on the left-hand side. For visualization purposes, note that the term structure is presented as the opposite of the usual slope, i.e., 2-year minus 10-year. Consider the United States, Germany and Italy. It is quite apparent that, especially for the U.S., the difference between the two bond spreads widens when the term structure slope steepens. While this result visually confirms the regressions of Table 1B and Table 2B, a nice feature of Figure 1 is that the spread measures track each other quite closely when the term structure is flat. This result is comforting to the extent it suggests the two measures are capturing a common effect, namely liquidity. With respect to Italy (and, for that matter, Spain), note that there is a considerable period from 2009 to 2013 in which both spread measures are negative. This period coincides with the Euro crisis and, in particular, the sovereign debt crisis of the Eurozone periphery, including Italy and Spain. Of course, the spreads, by construction, have no exposure per se to credit risk, so the credit difficulties of Italy and Spain must be proxying for other relevant market conditions.

As a measure of liquidity, along with calculating the spread between the most recently issued bond and matched off-the-run bonds, it is popular to look at the bid-ask spread of the bond as a sign of its liquidity. It should therefore be the case that the on-the-run bond's bid-ask spread should correspond to tighter spreads than its off-the-run counterparts. Unfortunately, bid-ask spreads are not accessible for a given tenor and across all the countries over the entire sample period. However, this data is available since May 9th 2012 from DSFI at Thomson Reuters.

Table 3 documents the results. Most important, for 10 of the 11 countries, the average bid-ask spread of the two most recent off-the-run bonds is higher than that of the on-the-run bond.[6] Intuitively, the most recently on-the-run bond should be more liquid and this is confirmed by bid-ask data albeit over a shorter time period. Moreover, for 9 of these countries, the difference is significant at 10% p-values and, for 7 countries, at 5% p-values. As additional evidence, Table 3 documents that, over this sample period, the on-the-run bond has a lower bid-ask spread the majority of the time for 10 of the 11 countries, ranging from 54% to 83% of the time. It should be noted that there are periods when the bid-ask spreads are the same. Independent of the above point on the relative liquidity between on-the-run and off-the-run bonds, the absolute level of the spreads are quite small and close together. For example, for the United States 10-year bond market, the quoted spreads are 0.23 basis points for the on-the-run versus 0.29 basis points for the off-the-run.

While the OTR-spread on average captures the positive spread between off-the-run and on-the-run bonds, a perusal of the OTR-spread, however, shows that the spread is sometimes negative, and varies both through time and cross-sectionally. Other than measurement error, what can explain such behavior of the OTR-spread?

As a first pass at the OTR-spread data, Table 4A documents the *unconditional* variance-covariance matrix of the OTR-spreads between the 11 countries in our sample. Some striking

[6] For this time period (i.e., post May 2012), the exception is Germany. For the majority of this period, the latest off-the-run 10-year bond was the cheapest-to-deliver bond in the corresponding futures contract, thus, adding to its liquidity.

characteristics are apparent. First, the correlations are quite low in the cross-section. If there is a common global liquidity factor, then it is either inconsequential (i.e., infrequent or small) or offset by other factors. For example, across the 55 correlations, the range goes from a low of -0.37 (between Spain and U.K.) to a high of 0.42 (between Spain and Italy). In absolute value, only 15 of the correlations are greater than 20%. Second, to the extent there are economically significant correlations, these correlations suggest an interesting pattern. For example, the Germany OTR-spread tends to be negatively correlated with other countries in Europe (such as Belgium, Spain, France, Italy and Sweden), yet positive with the Americas (such as Canada and the U.S.). At first glance, this seems surprising as one might expect that Europe would be subject to a common liquidity factor. Indeed, the OTR-spreads of Belgium, Spain, France and Italy are all positively correlated. As further evidence, Table 4B provides the first three principal components of the eleven developed countries. The first principal component captures almost 50% of the total variation of OTR-spreads. To the above point, the first component loads positively on Canada, Germany and United States and negatively on Belgium, Spain and Italy. The key driver of OTR-spreads therefore is unlikely to be a common factor but one with differential impact across the developed country landscape.

As we explain, and document in the next section, this differential effect can be explained in the context of a simple empirical model which highlights a perverse cost to holding the liquid bond in periods of stress.

III. Empirical Results: The Liquidity Across Sovereign 10-Year Bonds

In Section II above, we document several important characteristics of the OTR-spread. First, the spread is likely a good measure of liquidity and does not represent maturity mismatches. That is, in contrast to the typical spread between off-the-run and on-the-run bonds, variation of the OTR-spread measure is not explained by the term structure slope, duration or convexity. Moreover, for most of the countries, and majority of the periods, the estimated bid-ask spreads (albeit measures over a short time period) are lower for the most recently issued government bonds, also consistent with higher liquidity. Second, the OTR-spreads vary both cross-sectionally and through time which suggests that there does indeed exist variation that needs to be explained. Third, the unconditional correlation matrix of the 10-year OTR-spread across the 11 developed countries is generally inconsistent with a common liquidity factor being the most important driver of the OTR-spread variation. The reason is that the correlation between countries' OTR-spreads can be quite negative (e.g., -0.19 for Italy and Germany) and is only occasionally large and positive (e.g., 0.42 for Italy and Spain).

Below, we provide an empirical, and surprising, model for why this correlation pattern exists. As a preview, in this section, we explain the variation of OTR-spreads in terms of a "flight to quality" in the form of credit quality differences across countries as well as fund flows into and out of countries' sovereign bond markets. Note that by construction OTR-spreads do not have any credit risk embedded in them as the spread represents the difference of government bonds of the exact same credit quality (albeit of different liquidity). Thus, any explanatory power of credit quality for OTR-spread pricing must be due to credit quality across countries proxying for some other characteristic of sovereign bond markets.

The novel finding is that a "flight to quality" can be a "flight from liquidity" in those countries experiencing credit risk and suffering outflows of relevant investors. In other words, OTR-spreads, rather than increase, actually turn negative in higher credit risk countries as investors put pressure on the most saleable assets, namely the on-the-run benchmark bonds. In the introduction, we laid out a series of conditions for why the more liquid bond's price may fall below that of its less liquid bond counterpart:

- First, as capital flows into and out of sovereign government bond markets, the prices of the bonds will need to reflect the demand and supply imbalance to achieve equilibrium. If the on-the-run bonds are more easy to short, and generally cheaper to transact in, these shocks to capital flows will show up in the on-the-run bonds.
- Second, this price discovery will only breakdown if arbitrage is possible between the on-the-run and off-the-run markets. Specifically, in times of stress, the arbitrageur would purchase the cheaper on-the-run bonds and short the off-the-run bonds. If the short positions in the off-the-run bond cannot, however, be maintained, then segmented markets can lead to different prices (e.g., Boudoukh and Whitelaw (1993)).
- Finally, this argument suggests two reasons why on-the-run and off-the-run bonds may have different prices, both due to liquidity yet in opposite directions. On the one hand, there is the usual positive spread, reflecting cheaper transaction prices and lower inventory risk. On the other hand, in times of extreme downward price pressure, the benefits of liquidity can become a curse as

temporary price shocks show up in the liquid bond. Investors know this a priori and, therefore, even in normal times, the spread might be low or negative, depending on the probability of a price pressure episode.

Banerjee and Graveline (2013) provide a simple model which decomposes the liquidity premium, LP, of an asset into the sum of two components, namely the sum of the net premiums paid by the long and short side of the transaction. To be more concrete, consider two identical assets, *A* and *B*, with respective price P_A and P_B that differ by their liquidity, in particular, shorting capability. Following Banerjee and Graveline (2013), let δ be the share of the liquid asset, *A*, that is sold short, and let *R* be the refinancing premium (i.e., rebate rate) for lending to short sellers. The liquidity premium, *LP*, equals:

$$LP \equiv P_A - P_B = (1+\delta)\times\underbrace{(P_A - P_B)}_{\text{The liquidity premium paid by buyers of the asset}} - \delta\times\underbrace{R}_{\text{The financing premium earned by buyers of the asset}} + \delta\times\underbrace{(R - P_A + P_B)}_{\text{Short sellers pay the financing premium but sell at higher } P_A \text{ price}} \tag{1}$$

Feldhutter (2012) develops a model in which the price of two identical bonds can differ due to search costs and/or selling pressures associated with segmented small and large traders. Moreover, the theory of preferred habitat in the U.S. government bond market has been more formally derived and resulting supply effects have been empirically confirmed in specific circumstances (e.g., see Vayanos and Vila (2009) for a theoretical analysis and D'Amico and King (2013) and Greenwood and Vayanos (2013) for empirical studies). Therefore, in terms of equation (1), in normal times, *LP* is always positive reflecting search and other transactions costs. However, if there is intense selling pressure on the liquid asset, then this is not necessarily true anymore. Assume $P_A^* = P_A - \theta$ and $R^* = R + \varpi$, where θ represents the temporary price shock due to price pressure and ϖ is the additional premium due to the increase in shorting demand. Under these conditions, the new liquidity premium falls to $LP^* = LP - \theta$. The net premium paid by the long side falls by $(1+\delta)\times\theta + \delta\varpi$ which is partially offset by the higher costs of $\delta(\theta+\varpi)$ paid by shortsellers. The question empirically is the relative magnitudes of *LP* and θ.

a. Flight to Quality is a Flight from Liquidity

As a first look into the question of the pricing of OTR-spreads, we regress these spreads onto the idiosyncratic portion of a sovereign's credit, namely the difference between a given sovereign's CDS premium and the average cross-sectional premium across the countries. The regression methodology is a pooled, time-series analysis of 11 countries' 10-year OTR-spread over the period 2001 to 2015. The explanatory variable, the relative CDS spread of the sovereign (against a cross-sectional average), is the same one as that used by Beber, Brandt and Kavajecz (2008). In contrast to our use of this variable, however, they use it as their measure of credit risk of the sovereign bond. Specifically, in conjunction with various liquidity measures, they attempt to explain the spread between sovereign bonds and euro swaps into a credit and liquidity component. Their sample is short, covering just April 2003-December 2004. Nevertheless, they find strong evidence that the majority of sovereign yield spreads is driven by credit quality though liquidity also matters in times of increased market risk, especially in low credit risk countries.

Here, the CDS spread still represents credit quality of the country but we argue that credit quality has pricing implications for the sovereign bond's liquidity, independent of
credit risk. Specifically, consider the following regression model:

$$\text{OTR-spread}_{it} = \alpha + \beta\left(CDS_{it} - \tfrac{1}{N}\sum_{i}^{N} CDS_{it}\right) + \varepsilon_{it} \qquad (2)$$

where $\left(CDS_{it} - \tfrac{1}{N}\sum_{i}^{N} CDS_{it}\right)$ measures the relative credit quality across the N countries. The question equation (2) asks is how much of the variation of the OTR-spread both through time and across developed countries can be explained by the countries' relative credit quality.

Table 5 provides a surprising answer. In particular, the column labelled 3 of Table 5 documents the results of regression equation (2). The R^2 is 18.0% or, in words, a simple credit quality variable is 42% correlated with the OTR-spread. Given that the sample includes 15 years and many countries, the result is all the more remarkable. The coefficient is negative and statistically significant. Indeed, the sign of the coefficient suggests that if a country's credit quality is relatively low (high), that is, $\left(CDS_{it} - \tfrac{1}{N}\sum_{i}^{N} CDS_{it} > 0\right)$, then its OTR-spread will be lower. The coefficient of -0.03 implies that, for every 100 basis points of additional CDS premium, the OTR-spread will fall by 3 basis points. A nice finding from Table 5, however, is that the intercept is positive, implying a positive average OTR-spread.

That regression equation (1) can fully explain the cross-section seems a tall order. Credit quality aside, there might be specific characteristics of the liquidity of each country's bond market that is not common across countries. For example, in footnote 6, we cite the fact that the latest off-the-run bond in Germany during the period we measure bid-ask spreads is the cheapest to deliver bond in German bond futures markets. Column 4 of Table 5 presents regression equation (1) with country fixed effects. While there is no change in the coefficient on credit quality, the R^2 does jump to 23.1%, confirming important differences across countries.

Note that the relative credit quality $\left(CDS_{it} - \frac{1}{N}\sum_{i}^{N} CDS_{it} > 0\right)$ has two components, (i) a country's CDS premium which varies through time and in the cross-section, and (ii) an aggregate CDS premium which varies just through time. An interesting question is how much do these two components contribute to the variation of OTR-spreads. Table 5 provides a definitive answer. The column labelled 1 in Table 5 represents a regression of the OTR-spread on $\left(\sum_{i}^{N} CDS_{it}\right)$, while the column labelled 5 regresses OTR-spreads on $\left(\sum_{i}^{N} CDS_{it}\right)$ and $\left(CDS_{it} - \frac{1}{N}\sum_{i}^{N} CDS_{it}\right)$. With respect to both these regressions, the aggregate CDS premium does not have much explanatory power in terms of R^2 (e.g., 0.3% in column 1) and the coefficient estimate is not statistically significant (-0.39 in column 1). Variation through time in the OTR-spread does not seem to be related to moves in aggregate credit risk which is another blow to a common liquidity factor. Interestingly, when fixed effects are added to the regression on the aggregate CDS premium, the increase in R^2 is from 0.3% to 11.7%. This contrasts with a much smaller increase from 18.0% to 23.1% when we include fixed effects for the regression on the country specific CDS premium. This CDS premium therefore explains some of the country fixed effects of the OTR-spread as well as time variation of the OTR-spread.

The results of Table 5 show that liquidity can be a curse. The premium on the liquid bond is not just about the ability to transact, but also about receiving compensation for suffering price pressure episodes when the investor most wishes to sell the bond. Ironically, illiquid bonds do not reflect this pressure because investors are reluctant to transact, especially on the short side, because of getting stuck in the trade. In the subsections, we explore this issue more closely.

b. Price Pressure: Evidence

The results of Section III.a are novel to the literature and surprising in the context of common thinking about liquidity. We document that, as the credit quality of a country deteriorates (at least on a relative basis), its liquidity premium falls and goes negative. In other words, the liquid on-the-run bond *actually falls* in price relative to the less liquid off-the-run bonds when conditions are worsening. In terms of explanatory power, the correlation is over 42%, implying that these conditions are a key driver of the spread between likewise government bonds of different liquidity.

This extraordinary result begs the question – what is the possible explanation? We laid out one possible scenario at the beginning of this section based on episodes of price pressure. This theory leads to several additional implications that deserve scrutiny. If price pressure can explain the OTR-spread, then we should expect (i) to see that, in times of capital flows from "marginal" investors, the OTR-spread should be responsive to these flows, and (ii) during price pressure episodes, shocks to the OTR-spread should be temporary and driven by on-the-run, rather than off-the-run, bonds.

In this subsection, we investigate the above predictions to provide additional evidence for or against the price pressure hypothesis. Before performing this analysis, however, the behavior of the OTR-spreads could in theory be explained by stale pricing of the off-the-run bonds. When credit quality of a country deteriorates and investors move out of the country's government bonds, the OTR-spread can turn negative if the prices of the on-the-run bonds fall and, due to staleness, there is no corresponding move in the off-the-run bonds. We first address this issue.

On the surface, there are several reasons why staleness is unlikely to be a plausible explanation for the behavior of OTR-spreads. First, the OTR-spreads and country credit quality are persistent over several months. For example, other than Japan, the autocorrelation of OTR-spreads range from 0.82 to 0.93 at 1 week, 0.63 to 0.90 at 1 month, and 0.33 to 0.77 quarterly. Idiosyncratic CDS spreads persist even more, ranging from 0.96 to 0.99 at 1 week, 0.88 to 0.97 at 1 month, and 0.72 to 0.93 quarterly. In contrast, staleness would induce mean-reversion over relatively short horizons. Second, as documented in Table 3, the bid-ask spreads are not that different between on- and off-the-run bonds, thus, reducing one possible source of staleness in the off-the-run bonds.

Third, staleness in the off-the-run bond prices should show up as a lead-lag relation between the on-the-run and off-the-run bonds but not vice versa. Table 6A documents the weekly autocorrelation and cross-autocorrelations changes in the yields of the on-the-run and its hypothetical off-the-run counterpart. There is no evidence of staleness of the off-the-run relative to the-one-the run series. The cross-autocorrelation between lagged on-the-run yield changes and off-the-run yield changes are actually negative (albeit small) for 10 out of the 11 countries, the opposite implication of staleness. There is some slight evidence of negative autocorrelation of yield changes for both on-the-run and off-the-run bonds. While such a negative autocorrelation is consistent with stale pricing under a random walk model, it is also consistent with mean-reversion under temporary price pressure (and no stale pricing).

As pointed out by Boudoukh, Richardson and Whitelaw (1994) and others, however, it is not necessarily appropriate to simply document the cross-autocorrelation patterns of the two return series to infer the lead-lag relation. This is because if the two series are highly correlated (as is the case here), then lagged returns on one series simply proxies for lagged returns of the other series, obscuring the source of the nontrading bias. In this case, the correct regression is to perform a multivariate regression of the series' returns on the lags of both series. Table 6B reports the lead-lag relation between the on-the-run and constructed off-the-run bonds for each of the 11 countries. There is no evidence to suggest that either on- or off-the-run bonds lead each other; while the coefficients are more positive than negative, none are statistically significant at conventional levels. If anything, the off-the-run series shows slightly more evidence of leading with t-stats of 1.79 and 1.86 respectively for Spain and the U.K. Interestingly, for these two countries, the on-the-run series shows a significant lagged relation. As mentioned above, this is consistent with temporary price pressure.

For OTR-spreads to behave contrary to the standard liquidity theory requires temporary price pressure of the on-the-run bond. The existence of this pressure requires (i) limits to arbitrage, and (ii) buying or selling pressure. With respect to the former, we have argued above that shorting difficulties for off-the-run bonds implies some limits to arbitrage. With respect to the latter, if bonds are in fixed supply, it is well-known that it is not straightforward to determine the trading direction (i.e., "pressure") underlying the transaction. In this section, we use State Street Associates' dataset on the aggregated activities of institutional investors in terms of their net flows into and out of sovereign government bonds as a proxy for buying and selling pressure. (See, for example, Froot, O'Connell and Seasholes (2001) and Froot, Bhargava, Cuipa and Arabadjis (2014)).

State Street Corporation is one of the largest global custodians, with $25.7 trillion of assets under custody, capturing 15% of the global market (as of June 30, 2013). State Street argues that these assets represent a homogenous group of investors, so-called "real money", which are made up of primarily large global institutional investors, including mutual funds, pensions, foundations and endowments. Of some note, State Street's clients generally do not include corporations, retail investors, hedge funds or central banks. State Street takes each security-level transaction by the institutional investor and anonymously aggregates these transactions. For our purposes, each transaction in a country's sovereign government bonds are calculated as the difference in dollar value of buys minus sells at a given time t. State Street then takes a 5-day exponential average of these net flows and converts these flows into a percentile based on the last five years of data. The sample starts in November 2005.

Table 7 provides summary statistics for the net flows of sovereign government bonds across 10 developed countries.[7] Table 7A reports the mean, standard deviation, autocorrelation and principal component attribution of the net flow series. Recall that the net flows represent a value of 0 (outflows) to 1 (inflows) as a percentile of past net flows. Not surprisingly, over the sample period, the net flows, almost by construction, average around 0.5. The standard deviation suggests a fair amount of variation, hovering around 0.25. While the flows are on average autocorrelated 0.61 at weekly horizons, the autocorrelation at 4 weeks is significantly less, i.e., 0.13.

Of particular importance, similar to OTR-spreads, there is little evidence of a common factor. Table 7B documents that the first principal component captures only 18% of the variation and represents most of its weight interestingly on Spain and Italy. Thus, the first component to flows focuses very much on the periphery of the Eurozone countries, similar in many ways to the behavior of OTR-spreads and sovereign CDS described above. As such, Table 7C documents the correlation matrix of the net flows. The correlations are not particularly high though the highest correlation, i.e., 0.29, occurs for Italy and Spain. This is consistent with a flight away from low quality countries as represented by Italy and Spain. As a first pass at the relation between OTR-spreads and net flows, we estimate the pairwise correlation for each country. Though not shown

[7] The net flow data for Swedish government bonds is not available, thus, restricting our analysis to 10 of the 11 countries.

here, the correlation is mildly positive for Italy (i.e., 0.14) and negative for Germany (i.e., -0.11) and United States (-0.27). Of some interest is that the highest correlation is for Italy, the country in our sample with the highest credit risk. Somewhat puzzling is the finding that both the "safe haven" countries, namely Germany and United States, have negative correlation between flows and OTYR-spreads. The fact that these countries have different liquidity properties than the other countries is perhaps not surprising, but the nature of these properties are.

For a more formal empirical analysis, Table 8 runs variants of regression equation (2), yet now including net flows, defined as NF_{it}, as an explanatory variable:

$$\text{OTR-spread}_{it} = \alpha + \beta\left(CDS_{it} - \tfrac{1}{N}\sum_{i}^{N} CDS_{it}\right) + \gamma\left(NF_{it} - \tfrac{1}{N}\sum_{i}^{N} NF_{it}\right) + \varepsilon_{it} \quad (3)$$

Several observations are in order. First, even though the sample period is now different (i.e., starting in November, 2005), the coefficient estimates of β and the R^2 are similar to the longer sample described in Table 5. In particular, credit quality remains a key and important explanatory variable. Second, the coefficient on net flows, γ, is positive though albeit with a t-statistic of 1.60. In other words, if a country's net flows relative to the average is negative (positive), the OTR-spread is negative (positive). In other words, relative outflows (inflows) cause the liquid bond to become cheap (expensive) relative to the less liquid counterpart. This result is consistent with the price pressure story. Third, when both $\left(NF_{it} - \tfrac{1}{N}\sum_{i}^{N} NF_{it}\right)$ and $\left(\tfrac{1}{N}\sum_{i}^{N} NF_{it}\right)$ are included in the regression, the coefficients are both positive and the t-statistics become marginally significant for both with the common flow variable being more important. The results are again consistent with price pressure. Finally, Table 7B shows a differential correlation pattern between net flows and OTR-spreads for the so-called safe haven countries of the United States and Germany. In the columns labelled 7 and 8, Table 8 runs regression (3) but now separates out the net flows of the safe haven countries, creating two coefficients γ_{safe} and γ_{other}. Perhaps, not surprisingly, γ_{other} is positive, increases sharply and is now strongly significant, while γ_{safe} is negative and highly significant. This again highlights the differences of liquidity behavior between the safe haven and other countries.

Recall that the OTR-spreads are on average positive; less liquid bonds do command higher premiums. We argue and provide evidence that the OTR-spreads, however, are sufficiently responsive to price pressure episodes that the OTR-spreads can fall and even go negative at precisely times we might expect OTR-spreads to increase. As described above, temporary price pressure implies that shocks to OTR-spreads should mean-revert. Indeed, weekly changes in OTR-spreads are negatively autocorrelated for all eleven countries, in particular, for Germany -0.24, Belgium -0.13, Canada -0.18, Spain -0.36, France -0.38, Italy -0.26, Japan -0.22, Netherlands -0.44, Sweden -0.13, UK -0.15 and the U.S. -0.13.

c. Common Liquidity Factor

The variance-covariance matrix of OTR-spreads documented in Table 4 and the regression results of Table 5 do not provide much support for a common liquidity factor driving on-the-run versus off-the-run yield differentials. Nevertheless, note that the residuals from the regression in Table 5 represent the OTR-spread minus the component tied to a country's relative credit quality. Because the impact of credit quality varies cross-sectionally across the countries, it is possible that a common liquidity factor (albeit smaller in magnitude) may be hidden. A first pass suggests little evidence for this argument. The first principal component of the residuals covers 34% and the weights are scattered across countries and not suggestive of a common, equally-weighted, component.

To understand this issue more formally, we analyze the explanatory power of two common measures of liquidity, namely the TED spread (the spread between Libor and T-bills) and the CP spread (the spread between AA commercial paper rates and the Fed funds rate). Table 9 reruns regression equation (2) but now adding these common liquidity measures.

$$\text{OTR-spread}_{it} = \alpha + \beta\left(CDS_{it} - \tfrac{1}{N}\sum_{i}^{N} CDS_{it}\right) + \delta LF_t + \varepsilon_{it} \qquad (4)$$

where LF_t is the common liquidity factor, either the TED or CP spread. A number of observations are in order. First, the coefficient on the common liquidity factor, δ, is negative with a t-statistic of -2.10 for the CP-spread and -2.33 for the TED-spread. On the surface, this result is surprising. Assuming that credit quality captures the price pressure component, one might expect the common liquidity factor to explain the more standard liquidity premium on bonds, namely higher OTR-spreads during liquidity events. Second, to coincide with the net flow results of Table 8, Table 9 investigates the behavior of the safe haven countries of the United States and Germany compared to the rest of the developed countries. In the columns labelled 7 and 8, Table 9 runs regression (4) but now separates out the coefficients of the safe haven countries, creating two coefficients δ_{safe} and δ_{other}. Consistent with standard intuition, δ_{safe} is positive and statistically significant. When the liquidity factor increases, the OTR-spreads on U.S. and German bonds increase. In other words, the liquid bonds become more expensive. The opposite occurs for the other countries - δ_{other} continues to be negative and statistically significant -, again suggesting that these other countries are more likely to observe an exodus from their liquid bonds, leading to relatively cheaper pricing.

IV. Empirical Results: The Liquidity Across the Sovereign Term Structure

Our best explanation for the results of Section III is that, for many countries, there are liquidity or credit events that force temporary price pressure onto the more liquid bonds. This is ironic because normally we consider liquidity to help in times of crisis; here, it hurts. A burgeoning literature on the preferred habitat theory, however, might not be surprised by our findings (e.g., Vayanos and Vila (2009), Feldhutter (2012) and Greenwood and Vayanos (2014)). In these frameworks, markets are segmented and demand/supply effects can become important as different investors face differential shocks.

Motivated by the preferred habitat theory, a natural extension to the analysis of Section III would be to consider different maturity tenors across the developed countries. Fortunately, we are able to create OTR-spreads for multiple tenors across five countries – Germany, France, Italy, Japan and the United States. Appendix A2 describes the issuance cycle of these tenors. Appendix A3 documents the properties of the OTR-spread for each tenor, country by country. Not surprisingly, as the tenors are shorter maturity (e.g., 2-yr and 5-yr), the number of on-the-run bonds are greater than the 10-year total over the sample period. The issuance cycle is generally less. Consistent with Table 2, the OTR-spreads for the other tenors are on average positive except for Japan and Italy (which are marginally negative). The absolute value of the average spread is lower than that of the 10-year bond while the volatility of the shorter horizon OTR-spreads tend to be wider. Though not true across all the countries, the persistence tends to be a little less at the shorter horizons. In other words, there are differences across the term structure.

Nowhere does this manifest itself more than the cross-correlation across tenors country by country. In particular, consider the correlation between the OTR-spreads for the 10-yr and 5-yr tenors for each of the five countries. While the correlation between the actual yields is expectedly high ranging from 0.98, 0.97, 0.95, 0.91 and 0.99 for Germany, France, Italy, Japan and United States, respectively, the correlation between the OTR-spreads are quite low – Germany 0.13, France 0.03, Italy 0.35, Japan -0.08 and United States 0.33. Similar to the results above with respect to the cross-section of countries, there seems to be little commonality in liquidity across tenors. While this lack of correlation could reflect the size of the measurement errors in OTR-spreads relative to fundamental differences across OTR-spreads, the result is consistent with what one might expect from segmented markets and demand/supply imbalances.

In order to provide further evidence of potential price pressure effects, we create two datasets. The first set focuses on conditions under which the marginal investor might buy/sell one tenor over another tenor. A popular strategy in fixed income markets is to "ride the yield curve" by going long the high yielding bond and short the low yielding one. Furthermore, this carry trade has been investigated empirically for fixed income markets (Fama and Bliss (1987), Campbell and Shiller (1991), Ilmanen (1995), Barr and Priestly (2004), Longstaff and Yu (2007), and Koijen, Moskowitz, Pedersen and Vrugt (2014), among others). In particular, we look at (i) a simple measure based on the yield difference between the two tenors, and (ii) a more sophisticated carry measure that looks at the income earned from a long-short trade assuming the term structure of interest rates remains the same. The idea is that there will be price pressure on the more liquid asset, so yield spreads or carry will correlated positively with corresponding differences in OTR-spreads. The second set focuses on the State Street Corporation's estimates of sovereign bond flows. Specifically, for four of the countries – Germany, France, Italy and the United States -, State Street provides a 5-day exponential average of net flows of specific maturity tenors and converts these flows into a percentile based on the last five years of data. We take the difference between the net flows of the 10-year minus the 5-year government bonds.

Table 10 presents the result for pooled regressions of the OTR-spreads of the 10-year minus the 5-year government bond on the above measures of price pressure across maturities. All three measures – yield differentials, carry, and net flow differentials – have the expected positive sign in support of the price pressure hypothesis. Only the former two, however, are significant at conventional levels. For example, the yield and carry measures have t-statistics of 4.00 and 11.22, respectively. While it is possible that the correlation between these measures and the OTR-spread differences is driven by common measurement error or some fundamental other than price pressure, it is not ex ante clear what this might be.

V. Conclusion

What drives the liquidity of sovereign bonds? Current thinking is that government bonds with almost identical cash flows can trade at different prices due to liquidity, and these differences extenuate during global crises. In contrast, according to results presented in this paper, there is little evidence of a common factor and global crises can actually lead to the opposite impact due to liquidity. In particular, when a country suffers credit deterioration and/or a flight to quality, bond spreads tighten and *actually go negative*. In other words, the liquid bonds become cheaper, not more expensive, than their less liquid counterparts. We offer an explanation based on temporary price pressure and provide empirical support using data on net flows of investors in sovereign bonds. Of some interest, we are able to reconcile the differential behavior of bond spreads of the U.S. and Germany versus Spain and Italy during the Eurozone crisis period.

An interesting question is whether the findings of this paper are endemic to the government bond market or can be applied elsewhere in capital markets. For example, consider the capital structure of a firm that includes many bonds of similar credit risk, yet of possible different liquidity. When a corporation suffers financial distress (or, more broadly, a credit crisis occurs), what happens to the yield spreads between different bonds of the firm? The current view is that the spread would widen as the illiquid bond falls in value; the results in this paper suggest the opposite. Pulvino and Stafford (2013) provide an analysis of the financial crisis and the CDS-bond basis, which suggests that corporates and governments may be different. We leave this topic, and related ones on this liquidity anomaly, to future research.

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Table 1: Yield Spreads

Table 1A documents summary statistics for the spread between the latest off-the-run and on-the-run 10-year bond across 11 developed countries over the period 1998-2015. The represented countries are BD (Germany), BG (Belgium), CN (Canada), ES (Spain), FR (France), IT (Italy), JP (japan), NL (Netherlands), SD (Sweden), UK (United Kingdom) and US (United States). Table 1B reports pooled time-series regressions of the spread on a local measure of the term structure slope, as well as estimates of duration and convexity.

Table 1A Summary Statistics of Yield Spreads

	BD# 10	BG# 10	CN# 10	ES# 10	FR# 10	IT# 10	JP# 10	NL# 10	SD# 10	UK# 10	US# 10
00# of Obs	912	912	912	912	912	912	912	912	693	912	1,173
01Average	-2.8	-10.1	-7.0	-7.5	-5.9	-6.5	-2.2	-9.1	-8.5	-1.7	0.8
02Vol	1.1	2.5	1.4	4.0	1.9	2.8	2.1	1.7	1.3	2.1	1.4
03Min	-10.1	-43.2	-24.0	-58.1	-22.8	-41.9	-19.7	-22.1	-20.6	-36.3	-16.9
04Max	8.6	11.2	16.0	29.8	12.2	13.6	26.0	1.4	9.4	48.5	17.1
05 5th %	-7.1	-25.4	-15.1	-18.8	-12.9	-19.1	-7.3	-19.3	-16.9	-19.7	-4.7
06 95th %	1.7	-1.2	0.4	-0.4	-0.3	3.0	2.1	-1.1	0.6	32.5	8.5

Table 1B: Regression of Yield Spread on Term Structure Slope

		1	2	3
Local Slope	beta	0.83		0.87
	tstat	71.37		76.86
Duration	beta		-15.32	-10.33
	tstat		-14.31	-18.52
Convexity	beta		1.01	0.36
	tstat		14.56	9.16
r2		65%	21%	68%
r2 net of FE		61%	7%	62%

Table 2: OTR-Spreads

Table 2A documents summary statistics for the OTR-spread (the difference of yields between a hypothetical bond priced by the off-the-run curve minus its on-the-run counterpart), i.e., $OTR - spread = y^{hyp} - y^{actual} = \frac{price^{hyp} - price^{actual}}{price^{hyp} \cdot duration}$, for the 10-year bond across 11 developed countries over the period 1998-2015. The represented countries are BD (Germany), BG (Belgium), CN (Canada), ES (Spain), FR (France), IT (Italy), JP (japan), NL (Netherlands), SD (Sweden), UK (United Kingdom) and US (United States). Table 2B reports pooled time-series regressions of the spread on a local measure of the term structure slope, as well as estimates of duration and convexity.

Table 2a Summary Statistics of OTR-Spreads

	BD#10	BG#10	CN#10	ES#10	FR#10	IT#10	JP#10	NL#10	SD#10	UK#10	US#10
00# of Obs	912	912	912	912	912	912	912	912	912	912	1,173
01Average	2.2	0.4	3.8	0.3	0.1	-2.6	-0.4	3.1	0.3	0.7	2.9
02Vol	1.0	2.3	1.9	3.4	1.6	3.0	2.0	1.7	1.3	1.8	1.5
03Min	-4.0	-22.8	-13.2	-35.6	-10.9	-40.6	-27.1	-7.2	-19.4	-19.6	-17.5
04Max	10.0	32.2	19.6	32.3	13.1	17.2	9.8	22.3	14.4	14.6	18.7
05 5th %	-0.5	-8.3	-2.7	-9.6	-3.8	-16.3	-2.8	-1.5	-10.6	-4.3	-2.4
06 95th %	5.8	7.4	12.9	7.7	4.2	7.3	1.9	9.6	8.4	8.6	9.8
07rho(1)	0.88	0.91	0.93	0.85	0.82	0.92	0.72	0.91	0.97	0.89	0.93
08rho(4)	0.67	0.73	0.78	0.71	0.63	0.82	0.04	0.83	0.90	0.67	0.77
09rho(12)	0.33	0.55	0.50	0.35	0.34	0.50	0.03	0.72	0.77	0.53	0.50
10rho(24)	0.29	0.45	0.25	0.22	0.21	0.36	0.04	0.57	0.59	0.39	0.46

Table 2b: Regression of Yield Spread on Term Structure Slope

		1	2	3
Local Slope	beta	-0.15		-0.10
	tstat	-13.20		-9.26
Duration	beta		-6.35	-6.95
	tstat		-10.66	-11.60
Convexity	beta		0.05	0.13
	tstat		1.25	3.06
r2		16%	22%	24%
r2 net of FE		5%	4%	6%

Table 3: Bid-Ask Spreads

Table 3 summary statistics for the bid-ask spreads for the 10-year on-the-run bond and average of two latest off-the-run bonds across 11 developed countries over the period May 2012-2015. The represented countries are BD (Germany), BG (Belgium), CN (Canada), ES (Spain), FR (France), IT (Italy), JP (japan), NL (Netherlands), SD (Sweden), UK (United Kingdom) and US (United States).

Table 3 On-the-run and Liquidity (bid-ask spread)											
	BD#10	BG#10	CN#10	ES#10	FR#10	IT#10	JP#10	NL#10	SD#10	UK#10	US#10
0% Average on-the-run bid-ask spread (bps)	0.43	0.93	0.84	1.78	0.73	1.00	0.75	0.78	2.17	0.52	0.23
1% Average off-the-run bid-ask spread (bps)	0.38	1.09	0.90	2.17	0.77	1.26	0.75	0.81	2.42	0.59	0.29
2% t-stat of diff	4.43	-1.49	-1.43	-6.70	-1.63	-6.48	-0.05	-2.43	-3.48	-4.84	-5.47
3% p-value of diff > 0	1.00	0.07	0.08	0.00	0.05	0.00	0.48	0.01	0.00	0.00	0.00
4% of On the run with higher bid-ask spread	69%	39%	38%	24%	36%	18%	37%	35%	13%	12%	15%
5% of On the run with lower bid-ask spread	20%	54%	62%	75%	62%	82%	54%	56%	73%	81%	83%
6 t stats of diff	5.18	-1.36	-2.18	-5.06	-2.32	-6.51	-1.70	-2.09	-4.94	-7.51	-7.26
7 p-value on the run has higher bid-ask spread	100%	9%	1%	0%	1%	0%	4%	2%	0%	0%	0%
8# of Obs	164	164	164	164	164	164	164	164	164	164	164
9 First Available Date for Bid-Ask	9-May-12	9-May-12	9-May-12	9-May-12	9-May-12	9-May-12	9-May-12	9-May-12	9-May-12	9-May-12	9-May-12

Table 4: Correlation Matrix of OTR-Spreads

Table 4A documents the correlation matrix for the OTR-spread (the difference of yields between a hypothetical bond priced by the off-the-run curve minus its on-the-run counterpart), i.e., $OTR - spread = y^{hyp} - y^{actual} = \frac{price^{hyp} - price^{actual}}{price^{hyp} \cdot duration}$, for the 10-year bond across 11 developed countries over the period 1998-2015. The represented countries are BD (Germany), BG (Belgium), CN (Canada), ES (Spain), FR (France), IT (Italy), JP (japan), NL (Netherlands), SD (Sweden), UK (United Kingdom) and US (United States). Table 4B documents the first three principal components underlying the OTR-spread data over the sample period

Table 4A Correlation Matrix of Level of 10 Yr OTR-Spreads

	BD	BG	CN	ES	FR	IT	JP	NL	SD	UK	US
BD	1.00	-0.14	0.35	-0.06	-0.17	-0.19	-0.21	0.01	-0.13	0.03	0.28
BG	-0.14	1.00	-0.14	0.23	0.34	0.43	0.06	-0.29	0.00	0.01	0.03
CN	0.35	-0.14	1.00	-0.09	0.04	-0.25	0.13	0.00	0.20	0.05	0.13
ES	-0.06	0.23	-0.09	1.00	-0.01	0.42	0.00	-0.20	-0.18	-0.37	0.02
FR	-0.17	0.34	0.04	-0.01	1.00	0.11	0.17	-0.04	0.40	-0.11	-0.05
IT	-0.19	0.43	-0.25	0.42	0.11	1.00	0.14	-0.14	0.03	-0.03	-0.01
JP	-0.21	0.06	0.13	0.00	0.17	0.14	1.00	-0.10	0.01	0.09	-0.03
NL	0.01	-0.29	0.00	-0.20	-0.04	-0.14	-0.10	1.00	0.35	0.03	-0.22
SD	-0.13	0.00	0.20	-0.18	0.40	0.03	0.01	0.35	1.00	0.05	-0.22
UK	0.03	0.01	0.05	-0.37	-0.11	-0.03	0.09	0.03	0.05	1.00	0.04
US	0.28	0.03	0.13	0.02	-0.05	-0.01	-0.03	-0.22	-0.22	0.04	1.00

Table 4B Principal Component Analysis of OTR-Spreads

%	BD	BG	CN	ES	FR	IT	JP	NL	UK	US
48.4	1.17	-2.09	2.39	-2.27	-0.12	-3.85	0.04	0.56	-0.08	0.66
19.1	-0.64	0.19	-1.94	-2.80	0.07	0.04	-0.05	0.00	0.59	-0.56
11.9	-0.39	-2.01	-1.48	0.97	-0.38	-0.52	-0.10	0.22	-0.25	-0.29

Table 5: Regression of OTR-Spreads on Credit Quality

Table 5 documents the regression of the OTR-spread (the difference of yields between a hypothetical 10-year bond priced by the off-the-run curve minus its on-the-run counterpart), i.e., $OTR - spread = y^{hyp} - y^{actual} = \frac{price^{hyp} - price^{actual}}{price^{hyp} \cdot duration}$, on different measures of credit quality across 11 developed countries over the period 2001-2015. Specifically, we run variants of the following regression model:

$$\text{OTR-spread}_{it} = \alpha + \beta\left(CDS_{it} - \tfrac{1}{11}\sum_{i}^{11} CDS_{it} \right) + \varepsilon_{it}$$

where $\left(CDS_{it} - \tfrac{1}{11}\sum_{i}^{11} CDS_{it} \right)$ measures the relative credit quality across the 11 countries.

Table 5 Level of 10 Yr OTR-Spread onto level of CDS							
Level							
		1	2	3	4	5	6
Intercept	beta	0.60	FE	0.35	FE	0.60	FE
	tstat	1.39		1.14		1.52	
CDS_i-CDS_m	beta			-0.03	-0.03	-0.03	-0.03
	tstat			-5.89	-5.59	-5.60	-5.15
CDS_m	beta	-0.01	-0.01			-0.01	0.00
	tstat	-0.39	-0.46			-0.76	-0.71
r2		0.3%	11.7%	18.0%	23.1%	18.3%	23.3%

Table 6: Lead-Lag Analysis of the On- and Off-the-Run Bonds

Table 6A documents the autocorrelation of changes in a hypothetical bond priced by the off-the-run curve and its on-the-run counterpart) for the 10-year bond across 11 developed countries over the period 1998-2015. The represented countries are BD (Germany), BG (Belgium), CN (Canada), ES (Spain), FR (France), IT (Italy), JP (japan), NL (Netherlands), SD (Sweden), UK (United Kingdom) and US (United States). Table 6B documents the multivariate analogous regression of the changes of the yields on these bonds against lagged changes of each bond.

Table 6A Does on-the-run yield lead off-the-run?

	BD#10	BG#10	CN#10	ES#10	FR#10	IT#10	JP#10	NL#10	SD#10	UK#10	US#10
0 On-the-run rho(1)	-0.03	-0.06	-0.02	-0.09	-0.04	-0.11	0.06	-0.04	-0.02	-0.07	-0.03
1 Off-the-run rho(1)	-0.04	-0.05	-0.06	-0.06	-0.03	-0.11	0.02	-0.04	-0.01	-0.06	-0.03
2 p-value off-the-run not more stale	81%	40%	100%	4%	31%	56%	86%	71%	12%	25%	36%
3 On-the-run lead	-0.03	-0.06	-0.05	-0.07	-0.02	-0.09	0.06	-0.03	-0.01	-0.06	-0.03
4 Off-the-run lead	-0.03	-0.05	-0.02	-0.06	-0.03	-0.11	0.03	-0.03	-0.02	-0.05	-0.03
5 p-value off-the-run tends to lead	67%	76%	98%	71%	15%	27%	25%	51%	35%	76%	36%
6 # of Obs	910	910	910	910	910	910	910	910	903	910	1171

Table 6B Does on-the-run yield lead off-the-run?

		BD#10	BG#10	CN#10	ES#10	FR#10	IT#10	JP#10	NL#10	SD#10	UK#10	US#10
Intercept	**beta**	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	tstat	-1.45	-1.23	-1.20	-0.78	-1.25	-0.70	-0.59	-1.35	-1.25	-1.21	-0.98
lag	**beta**	-0.36	0.00	-0.25	0.13	-0.25	-0.30	-0.37	-0.28	0.08	-0.07	-0.06
	tstat	-1.06	0.00	-1.55	0.46	-1.54	-1.29	-1.17	-1.14	0.29	-0.46	-0.24
lead	**beta**	0.33	-0.06	0.20	-0.19	0.22	0.19	0.41	0.24	-0.10	0.01	0.03
	tstat	0.98	-0.37	1.20	-0.70	1.42	0.76	1.37	1.00	-0.34	0.07	0.10
r2		0.4%	0.3%	0.5%	0.6%	0.4%	1.5%	1.7%	0.4%	0.0%	0.4%	0.1%

Table 6B Does off-the-run yield lead on-the-run?

		BD#10	BG#10	CN#10	ES#10	FR#10	IT#10	JP#10	NL#10	SD#10	UK#10	US#10
Intercept	**beta**	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	tstat	-1.41	-1.25	-1.18	-0.76	-1.28	-0.84	-0.70	-1.35	-1.28	-1.16	-0.96
lag	**beta**	-0.09	-0.23	-0.02	-0.56	-0.16	-0.05	0.28	-0.11	-0.29	-0.35	-0.05
	tstat	-0.30	-1.49	-0.15	-2.14	-0.96	-0.19	1.04	-0.49	-1.03	-2.38	-0.19
lead	**beta**	0.06	0.17	0.00	0.49	0.12	-0.06	-0.23	0.08	0.27	0.29	0.01
	tstat	0.21	1.14	-0.01	1.79	0.70	-0.26	-0.83	0.33	0.96	1.86	0.05
r2		0.1%	0.6%	0.1%	2.3%	0.2%	1.2%	0.9%	0.2%	0.2%	1.0%	0.1%

Table 7: Net Flows

Table 7A documents summary statistics for the net flows of sovereign government bonds across 10 developed countries from November 2005-2015. The data is provided by State Street Corporation. Each transaction in a country's sovereign government bonds are calculated as the difference in dollar value of buys minus sells at a given time t. State Street then takes a 5-day exponential average of these net flows and converts these flows into a percentile based on the last five years of data. The represented countries are BD (Germany), BG (Belgium), CN (Canada), ES (Spain), FR (France), IT (Italy), JP (japan), NL (Netherlands), UK (United Kingdom) and US (United States). Table 7B reports a principal component analysis of the net flows, and Table 7B an estimate of the correlation matrix of net flows, cross-sectionally demeaned each period.

Table 7A Summary Statistics of Flows										
	BD#10	**BG#10**	**CN#10**	**ES#10**	**FR#10**	**IT#10**	**JP#10**	**NL#10**	**UK#10**	**US#10**
00# of Obs	496	496	496	496	496	496	496	496	496	496
01Average	0.50	0.49	0.47	0.53	0.45	0.53	0.50	0.48	0.45	0.52
02Vol	0.22	0.24	0.20	0.26	0.22	0.25	0.20	0.24	0.16	0.20
03Min	0.00	0.01	0.01	0.00	0.00	0.00	0.01	0.00	0.01	0.02
04Max	1.00	0.99	1.00	1.00	0.99	1.00	0.99	1.00	0.99	1.00
05 5th %	0.06	0.08	0.14	0.04	0.08	0.05	0.12	0.07	0.13	0.10
06 95th %	0.93	0.90	0.91	0.97	0.87	0.94	0.92	0.93	0.83	0.94
07rho(1)	0.64	0.53	0.63	0.64	0.55	0.64	0.62	0.58	0.68	0.64
08rho(4)	0.07	-0.01	0.10	0.18	0.12	0.15	0.22	0.04	0.17	0.25
09rho(12)	-0.08	0.00	-0.01	0.03	0.05	0.04	0.24	-0.01	0.10	0.08
10drho(24)	0.02	-0.13	0.10	-0.07	0.01	-0.01	0.18	0.01	0.09	-0.17

Table 7B PC's for Flows										
	Variance %	**BD#10**	**BG#10**	**CN#10**	**ES#10**	**FR#10**	**IT#10**	**JP#10**	**UK#10**	**US#10**
1st	18%	0.00	-0.12	0.03	-0.74	-0.04	-0.65	-0.05	-0.09	-0.01
2nd	15%	0.51	0.26	-0.01	-0.23	0.37	0.16	0.34	0.10	-0.04
3rd	11%	-0.55	0.52	0.27	-0.34	-0.12	0.29	0.08	0.15	-0.35

Table 7C: Correlation Matrix of Net Flows

	BD#10	**BG#10**	**CN#10**	**ES#10**	**FR#10**	**IT#10**	**JP#10**	**NL#10**	**UK#10**	**US#10**
BD#10	1.00	-0.01	-0.03	-0.03	0.17	0.02	0.15	0.15	0.01	0.08
BG#10	-0.01	1.00	0.06	0.01	0.07	0.11	0.10	0.10	0.07	-0.04
CN#10	-0.03	0.06	1.00	-0.02	-0.11	-0.03	0.12	-0.03	0.13	-0.01
ES#10	-0.03	0.01	-0.02	1.00	0.00	0.29	-0.01	-0.08	0.04	0.07
FR#10	0.17	0.07	-0.11	0.00	1.00	0.05	0.13	0.20	0.02	-0.05
IT#10	0.02	0.11	-0.03	0.29	0.05	1.00	0.05	0.04	0.11	-0.07
JP#10	0.15	0.10	0.12	-0.01	0.13	0.05	1.00	0.10	0.22	0.01
NL#10	0.15	0.10	-0.03	-0.08	0.20	0.04	0.10	1.00	0.01	-0.03
UK#10	0.01	0.07	0.13	0.04	0.02	0.11	0.22	0.01	1.00	0.00
US#10	0.08	-0.04	-0.01	0.07	-0.05	-0.07	0.01	-0.03	0.00	1.00

Table 8: Regression of OTR-Spreads on Credit Quality & Net Flows

Table 8 documents the regression of the OTR-spread (the difference of yields between a hypothetical 10-year bond priced by the off-the-run curve minus its on-the-run counterpart), i.e., $OTR - spread = y^{hyp} - y^{actual} = \frac{price^{hyp} - price^{actual}}{price^{hyp} \cdot duration}$, on different measures of credit quality and net flows across 10 developed countries over the period 2005-2015. Specifically, we run variants of the following regression model:

$$\text{OTR-spread}_{it} = \alpha + \beta\left(CDS_{it} - \tfrac{1}{N}\sum_{i}^{N} CDS_{it}\right) + \gamma\left(NF_{it} - \tfrac{1}{N}\sum_{i}^{N} NF_{it}\right) + \varepsilon_{it}$$

where $\left(CDS_{it} - \tfrac{1}{N}\sum_{i}^{N} CDS_{it}\right)$ measures the relative credit quality across the 10 countries and net flows are defined as NF_{it}, average net flows are NF_{mt}, and net flows of safe haven countries (Germany and U.S.) $NF_{it:safe}$.

Table 8 Level of 10 Yr OTR-Spread onto Flow									
Level									
		1	2	3	4	5	6	7	8
Intercept	beta	0.35		0.35		-0.80		-0.77	
	tstat	0.79		0.79		-1.08		-1.04	
CDS_i	beta	-0.03	-0.03	-0.03	-0.03	-0.03	-0.03	-0.03	-0.03
	tstat	-5.63	-7.33	-5.65	-7.33	-5.66	-7.58	-5.68	-7.60
Flow_i	beta			0.58	0.39	0.58	0.39	0.96	0.78
	tstat			1.60	0.95	1.61	0.97	2.76	1.96
Flow_m	beta					2.35	2.30	2.30	2.25
	tstat					2.12	1.97	2.10	1.95
Flow_i_Safe	beta							-1.88	-1.90
	tstat							-4.53	-4.21
r2		19.0%	27.3%	19.1%	27.3%	19.3%	27.5%	19.4%	27.6%

Table 9: Regression of OTR-Spreads on Credit Quality & Global Liquidity

Table 9A documents the regression of the OTR-spread (the difference of yields between a hypothetical 10-year bond priced by the off-the-run curve minus its on-the-run counterpart), i.e., $OTR - spread = y^{hyp} - y^{actual} = \frac{price^{hyp} - price^{actual}}{price^{hyp} \cdot duration}$, on different measures of credit quality and a global liquidity factor (i.e., TED-spread or Commercial Paper –spread) across 11 developed countries over the period 2001-2015. Specifically, we run variants of the following regression model:

$$\text{OTR-spread}_{it} = \alpha + \beta\left(CDS_{it} - \tfrac{1}{N}\sum_{i}^{N} CDS_{it}\right) + \delta LF_t + \varepsilon_{it}$$

where $\left(CDS_{it} - \tfrac{1}{11}\sum_{i}^{11} CDS_{it}\right)$ measures the relative credit quality across the 11 countries and LF_t is the common liquidity factor, either the TED or CP spread. Table 9B allows a differential coefficient for safe haven countries (Germany and U.S.).

Table 9 Regression on Credit Quality & Global Liquidity							
Level							
		1	2	3	4	5	6
Intercept	beta	0.59	FE	0.85	FE	0.84	FE
	tstat	1.84		2.42		2.41	
CDS_i	beta	-0.03	-0.03	-0.03	-0.03	-0.03	-0.03
	tstat	-5.99	-5.71	-6.05	-5.77	-6.05	-5.77
CP	beta	-1.25	-1.29			-0.19	-0.27
	tstat	-2.10	-2.14			-0.49	-0.73
TED	beta			-1.02	-1.02	-0.93	-0.89
	tstat			-2.33	-2.29	-2.35	-2.21
r2		18.5%	23.8%	19.0%	24.2%	19.0%	24.2%
Table 9 Regression on Credit Quality & Global Liquidity w/ Safe Haven							
Level							
		1	2	3	4	5	6
Intercept	beta	0.69	FE	0.68	FE	0.68	FE
	tstat	1.29		1.31		1.28	
CDS_i	beta	-0.03	-0.03	-0.03	-0.03	-0.03	-0.03
	tstat	-5.51	-5.34	-5.20	-5.66	-5.55	-5.40
Flow	beta					0.68	0.51
	tstat					2.18	1.51
TED	beta	-0.86	-0.85	-1.29	-1.31	-0.82	-0.83
	tstat	-1.65	-1.70	-2.94	-2.41	-1.63	-1.71
TED Safe	beta			2.19	2.29		
	tstat			4.32	3.56		
r2		19.8%	28.2%	21.5%	29.2%	19.9%	28.3%

Table 10: Regressions of the Term Structure Slope of OTR-Spreads onto Yield, Carry and Term Structure Slope of Net Flows

Table 10A documents the regression of the difference between OTR-spreads of different maturity, i.e., the difference of 10-yr and 5-yr difference in yields between a hypothetical bond priced by the off-the-run curve minus its on-the-run counterpart) on different measures of income differentials between the 10-year and 5-year bonds (either yield or carry) and differences of net flows of the 10-year and 5-year. The sample period is 2005-2015 and covers 10 countries. Table 10B adds fixed effects.

Table 10A		Level			
		1	2	3	4
Intercept	beta	-0.70	0.92	0.63	2.23
	tstat	-4.03	10.39	1.16	16.25
Yield	beta	0.01			
	tstat	4.00			
Carry	beta		0.03		0.06
	tstat		11.22		13.24
Flow	beta			0.35	0.33
	tstat			0.67	1.02
r2		0.5%	2.8%	0.1%	7.8%
# of Obs		4816	4816	1984	1984
Table 10B		Level w/ Fixed Effects			
		1	2	3	4
Yield	beta	0.01			
	tstat	5.09			
Carry	beta		0.05		0.05
	tstat		14.82		12.68
Flow	beta			0.11	0.19
	tstat			0.30	0.58
r2		6.2%	9.4%	5.9%	11.2%
# of Obs		4816	4816	1984	1984

APPENDIX - TABLES

Appendix A1 documents properties of the issuance cycle for the 10-year on-the-run bond across 11 developed countries over the period 1998-2015. The represented countries are BD (Germany), BG (Belgium), CN (Canada), ES (Spain), FR (France), IT (Italy), JP (japan), NL (Netherlands), SD (Sweden), UK (United Kingdom) and US (United States). Table A2 documents a similar graph, but for other maturity tenors. Table A3 documents summary statistics for these additional tenors.

Table A1 10Yr Point Issuances

	BD#10	**BG#10**	**CN#10**	**ES#10**	**FR#10**	**IT#10**	**JP#10**	**NL#10**	**SD#10**	**UK#10**	**US#10**
0Total Number	44	19	19	25	41	33	144	20	29	27	81
1Average Issuance Cycle	152	364	363	281	164	205	45	369	238	253	104
2Min Issuance Cycle	70	312	272	65	8	9	6	224	4	8	59
3Max Issuance Cycle	224	413	546	497	270	334	94	455	616	1030	186
4STD Issuance Cycle	40	19	57	131	72	72	22	51	206	263	33
5First Date	5-Jan-98	5-Jan-98	5-Jan-98	5-Jan-98	5-Jan-98	5-Jan-98	5-Jan-98	5-Jan-98	5-Jan-98	5-Jan-98	1-Jan-93

TABLE A2 Additional Points for Term Structure

	BD#02	**BD#05**	**FR#05**	**IT#03**	**IT#05**	**JP#05**	**US#02**	**US#05**
0Total Number	72	48	35	53	39	143	271	226
1Average Issuance Cycle	91	136	183	125	175	45	31	37
2Min Issuance Cycle	70	15	14	7	73	1	18	18
3Max Issuance Cycle	105	217	353	245	277	92	61	186
4STD Issuance Cycle	7	46	60	52	54	22	3	26
5First Date	5-Jan-98	5-Jan-98	5-Jan-98	5-Jan-98	5-Jan-98	5-Jan-98	1-Jan-93	1-Jan-93

TABLE A3 Summary Statistics for OTR Spreads of Other Tenors

	BD#02	BD#05	FR#05	IT#03	IT#05	JP#05	US#02	US#05
00# of Obs	912	912	912	912	912	912	1,173	1,173
01Average	1.1	1.1	0.1	-0.1	-0.4	-0.2	1.2	2.2
02Vol	3.4	1.3	2.1	3.9	3.2	1.0	1.5	1.2
03Min	-22.5	-11.3	-14.8	-38.2	-33.8	-9.8	-14.3	-12.1
04Max	21.8	14.4	19.6	30.6	30.3	8.2	14.5	14.9
05 5th %	-5.3	-2.8	-4.1	-11.7	-11.2	-3.0	-2.1	-1.2
06 95th %	7.6	6.1	3.4	9.8	6.8	2.2	4.9	9.6
07rho(1)	0.72	0.90	0.72	0.82	0.86	0.83	0.80	0.93
08rho(4)	0.47	0.63	0.52	0.57	0.72	0.41	0.61	0.80
09rho(12)	0.12	0.38	0.27	0.23	0.63	0.06	0.28	0.65
10drho(24)	-0.01	0.28	0.07	0.18	0.58	-0.13	0.11	0.59

FIGURE 1: On-the-Run Spreads

Figure 1 graphs the spread between the on-the-run and latest off-the-run bond, as well as the OTR-spread (the difference between a hypothetical bond priced by the off-the-run curve minus its on-the-run counterpart), i.e., $OTR - spread = y^{hyp} - y^{actual} = \frac{price^{hyp} - price^{actual}}{price^{hyp} \cdot duration}$, over the period 1998-2015. The spreads are graphed with the slope between the 2-year and 10-year government bond yields labelled on the right-hand side. The represented countries are BD (Germany), BG (Belgium), CN (Canada), ES (Spain), FR (France), IT (Italy), JP (japan), NL (Netherlands), SD (Sweden), UK (United Kingdom) and US (United States).