Sovereign Credit Quality and Violations of the Law of One Price

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Abstract:
It is well-documented that government bonds with almost identical cash flows can trade at different prices. This paper analyzes the cross-section of bond spreads across developed European countries and documents a novel result. In periods of widening credit spreads, bond spreads between new and old issues tighten for low quality sovereigns. In other words, the newer bonds become cheaper, not more expensive, relative to their older counterparts. We offer an explanation based on price pressure and provide empirical support using data on net flows of investors in sovereign bonds.

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I. Introduction

Numerous violations of the law of one price for financial assets (i.e., securities with almost identical cash flows trading at different prices) have been documented. There is arguably no better illustration of this phenomenon than that of government bonds, in particular, the higher pricing of the most recently issued bond versus a previously issued counterpart matched by maturity and cash flow.[1] The standard explanation for this pricing spread, denote the New Issue (NI) spread, is a premium for liquidity.[2] This paper offers an additional and novel source for the pricing of sovereign government bonds. In stressful periods, investors "fly" from the weak sovereigns, leading to a tightening, not widening, of the NI-spreads in these sovereigns' spreads. In other words, when investors become concerned about the creditworthiness of a country (i.e., its quality), they try to sell that country's bonds. This flight takes place in the most liquid instruments, pushing down the prices of the most liquid bonds relative to illiquid bonds of the weak sovereigns, leading to tightening NI-spreads.

We study the behavior of the NI-spread across a range of European countries over an extensive time period, 2006 to 2018.[3] We document that, in periods of changing credit spreads, NI-spreads of weakening (strengthening) sovereigns do indeed tighten (widen). For example, in a pooled time-series regression of NI-spreads on a country's changing credit quality, we document a significantly *negative* relation and R^2s on the order of 11% (and 26% with fixed effects). This result is surprising because, having the same credit risk, the sovereign bond's credit should not play a role in relative pricing. Moreover, there are prolonged periods in which the NI-spread (across multiple countries)

[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] The liquidity premium represents the value of trading newly issued bonds with immediacy, in relatively large quantities and at the prevailing price (or with a relatively small price impact). 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), Pasquariello and Vega (2009), Favero, Pagano and Von Thadden (2010), and Banerjee and Graveline (2013). The liquidity premium for bonds is discussed and analyzed in the context of "flight to liquidity" (i.e., sudden market-wide demand to hold liquid securities, e.g., Longstaff (2004), Vayanos (2004) and Goyenko, Subrahmanyam and Ukhov (2011)) and flight to quality" (i.e., sudden market-wide preference to decrease exposure to securities with credit risk, e.g., Beber, Brandt and Kavajecz (2009), Favero, Pagano and Von Thadden (2010), Bai, Julliard and Yuan (2012), Darbha and Dufour (2015), and Pelizzon, Subrahmanyam, Tomio, and Uno (2015)).

[3] As a byproduct, we develop a methodology to calculate the spread between new and old bond issues that accounts for the coupon and maturity mismatch (see also Longstaff (2004)). By construction, the spread reflects the relative pricing of government bonds that, within country, differ only by issuance date and, importantly, not by credit risk.

turns negative. What are the possible reasons for the behavior of the NI-spread when the credit quality of a sovereign changes?

We document two key stylized facts supporting a price pressure explanation.[4] First, investors tend to "fly" from sovereign bonds of deteriorating quality. The net flows into and out of sovereign government bonds by institutional investors (as measured by State Street Associates' dataset on the aggregated activity of institutional investors) are negatively correlated with changes in the credit quality of these bonds (as measured by their current CDS spread relative to a medium-term moving average). For example, the contemporaneous average correlation at 1-, 3- and 6-month horizons across the developed European countries is respectively -12%, -15% and -18%. Moreover, various model specifications of net flows and credit show a statistically significant relation. Second, our argument requires investors to first transact in their most liquid holdings to minimize price impact when shifting away from decreasing quality assets.[5] The selling (buying) pressure on the low (high) quality sovereigns then leads to temporary price movements in their liquid bonds, which at some later date are reversed. While we do not have data on investors' sales of liquid versus illiquid sovereign bonds, we provide empirical evidence consistent with temporary price pressure impacting the prices of liquid sovereign bonds. We conduct an event study around large credit shocks and indeed show that NI-spreads initially tighten for weak sovereigns. But these changes are only temporary and eventually pull back to some steady state. For example, the NI-spreads drop on average 25 basis points within a week of the event and take approximately 12 weeks to recover.

Our results are unexpected. Perhaps, some other pricing mechanism is at play. Stale pricing, i.e., liquid bonds responding more quickly than illiquid bonds to credit quality shocks, is one possibility (e.g., Scholes and Williams (1977)). Alternatively, the NI-spread could tighten during times of crisis due to changing liquidity and/or specialness of newly versus previously issued bonds (e.g., Vayanos and Weill (2008) and Banerjee and Graveline (2013)). We explore both of these explanations and

[4] The existence of price pressure in the market for government bonds has both theoretical (e.g., Vayanos and Vila (2009)) and empirical (e.g., D'Amico and King (2013), Greenwood and Vayanos (2010) and Beetsma, Giuliodori, Hanson and De Jong (2018)) support. There is a recent literature documenting price pressure in other bond markets, such as corporate bonds (e.g., see Mitchell, Pedersen and Pulvino (2007), Ellul, Jotikasthira and Lundblad (2011), Feldhutter (2012) and Cai, Han, Li and Li (2019)).

[5] This observation has been documented in a variety of settings (e.g., Scholes (2000), Ben-David, Franzoni and Moussawi (2012), Manconi, Massa and Yasuda (2012) and Jiang, Li and Wang (2017)).

find little support for them in the data. Ultimately, the evidence we present evidence points to the "price pressure" hypothesis, combined with some degree of segmentation within the bond market which does not allow "easy" arbitrage between the newly and previously issued bonds.[6]

II. Data Description

Our primary data source for European government bond prices is Data Scope Fixed-Income (DSFI) from Thompson Reuters, starting in January 2006 through June 2018. We process a total of 1781 treasury bonds and 3114 treasury bills issued by the largest issuers from developed European countries (Belgium, France, Italy, Germany, Netherlands, Spain and UK) and the United States as a benchmark. We use Bloomberg as our secondary data source when DSFI data is unavailable or discontinuous.[7] A typical measure of the quality of the sovereign is its credit default swap (CDS) spread. From Markit, we collect data on 5-year CDS spreads of the same eight countries over a similar January 2006 to June 2018 period.

The purpose of this paper is to investigate NI-spreads in sovereign bond markets by comparing the most recently issued bond to previously issued bonds of similar maturity and cash flows. Previous studies, especially involving U.S. Treasury markets, compare the most recently issued to the second most recently issued bond. International sovereign markets, however, present an important institutional challenge to this common procedure.

Unlike in the United States, a number of countries do not continually issue new bonds, but rather, reissue existing ones. In these cases, we need to identify not only the issuance date of each bond, but also reissuance (also known as re-opening) dates and quantities for each of the candidate bonds. Appendix A describes in detail the procedure, with supporting evidence in Tables A1A and A1B. As

[6] For a discussion of liquidity within different bond markets, see Boudoukh and Whitelaw (1993), Buraschi, Sener and Mengauturk (2010), Graveline and McBrady (2011) and Banerjee and Graveline (2013).

[7] An advantage of the DSFI data is its long time series compared to previous studies which focus on much shorter time intervals for sovereign government bonds, providing us more power to detect credit quality events. (For example, in previous work, the sample periods are 2002-2003 in Favero, Pagano and Von Thadden (2010), 2003-2004 in Beber, Brandt and Kavajecz (2009), 2006-2012 in Bai, Julliard and Yuan (2012), 2004-210 in Darbha and Dufour (2015) and 2011-2012 in Pelizzon, Subrahmanyam, Tomio, and Uno (2015).) Moreover, DSFI is the standard data source for marking books of portfolio managers, mutual fund administrators and custodians, among others. Thompson Reuters obtains data from various primary sources such as the Bridge EJV database and broker-dealers. In comparing the pricing of bonds using Thompson Reuters versus Bloomberg, weekly correlation of bond price changes of newly issued across these two sources and, similarly of most recent previously issued bonds, average 98.5%.

Table A1 shows, the issuance cycle is considerably longer for most country's 10-year bonds than U.S. bonds. A long issuance cycle means that newly issued and previously issued bonds will no longer have similar maturities and therefore any comparison of their yield spreads may be 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 price spread between the newly issued and the most recent previously issued bond.

Table 1 documents the properties of the naïve price spread (difference between new and previously issued bonds) country by country. To the above point, for all the countries, the average naïve price spread is actually negative. If the term structure is upward sloping over this period, and there is a sufficient gap in the issuance cycle, then there will be a bias towards a negative spread. In order to understand how important the bias is, note that the price difference between the newly issued bond and most recent previous issue is a combination of local slope of the yield curve and the liquidity premium of the new issue (or illiquidity discount of the older issue).

We use the curve based on prices of previous issues to price the newly issued bond and compute its hypothetical price if it were priced by the curve in line with previous issues. We construct the local slope measure as the most recent previous yield minus the hypothetical new issue yield. Liquidity aside, this slope measure captures the impact of time-to-maturity differences between the newly issued and previously issued bond. Table 2 reports regressions of the naïve 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 0.76 and explains an astonishing 59% of the variation of the naïve yield spread. Consistent with this finding, Table 2 also shows that the naïve price spread is related to duration and convexity. However, conditional on local slope, the R^2 only marginally increases. This reassures the thesis that a large part of the price spread is explained by the slope of the term structure and cash-flow differences between the two bonds.

A. New Issue Spread

As discussed above, the average yield spread between the new and most recently issued bond in all countries is negative, and this yield spread is highly sensitive to the slope of the term structure. These results are an outcome of the maturity and coupon mismatch between new and old issues. Any analysis of the spread between new bond issues and the most recent previous issue will therefore be difficult in light of the importance of the coupon and maturity mismatch, which is a well-known problem in trying to match bonds of different liquidity. (See Fleming (2002), 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 previously issued bonds of a given country. We then bootstrap a zero curve using only these bonds.[8] We compute a hypothetical price for each of the newly issued bonds assuming these bonds are priced by the same zero curve. The spread between the *hypothetical* bond (based on the previous issue zero curve) and the newly issued bond, denote *NI-spread*, is the shift in the zero curve that would price the bonds equally. Mathematically, *NI-spread* $= price^{hyp} - price^{actual}$.[9] A positive spread represents the premium newly issued bonds are priced at relative to a duplicate bond constructed from the term structure of older bonds. After correcting the NI-spread in this manner for the maturity mismatch, Table 2 documents that the coefficient estimate from regressing the NI-spreads on the term structure slope drops to -0.15 (albeit with a t-statistic of -3.13) and, net of country fixed effects, explains only 1% of the variation of the NI-spread. Thus, the NI-spread better corrects for the sensitivity to the slope of the term structure arising from the maturity mismatch. As an aside, outside of the specific context of this paper, this approach may prove useful for other comparisons of government bonds as it has the ability to put all bonds on the same cash flow-maturity footing.

[8] First, we group the bonds into different tenors (2, 3, 5, 7, 10, 15, 20, 30) by their time-to-maturity as of their most recent issuance. We remove the newly issued bond for each tenor as well as the aged ones (e.g., a 7 year bond having a time to maturity shorter than any of the 5 year bonds). Then we apply a standard bootstrapping procedure for all the on-the-run T-bills and the selected bonds with linear forward rate interpolation to obtain zero curves. By construction, the spread between the newly issued bond and a likewise hypothetical bond from this zero curve will generally be nonzero since the newly issued bonds are not included in the bootstrapping procedure.

[9] In yield space, the NI-spread is the difference of yields between a hypothetical bond priced by the older bond' curve minus its newly issued counterpart, i.e., $NI - spread = y^{hyp} - y^{actual} = \frac{price^{hyp} - price^{actual}}{price^{hyp} \cdot duration}$. We use the Fisher-Weil duration to capture the price sensitivity to the parallel shift of the yield curve (e.g., Fisher and Weil (1971)).

Table 1 documents the mean NI-spreads over the cross-section of countries. The range of average spreads varies from a low of -24.3 basis points for Italy to a high of 22.7 basis points for the U.S. To further gauge the magnitude of the spreads, Table 1 also reports the standard deviation of the NI-spread (in price terms) and the daily price volatility of each sovereign bond. For Belgium, Spain and Italy, the standard deviation of the NI-spread (respectively 20.4, 23.9 and 19.7) is comparable in size to the daily price volatility of the bond (respectively 38.1, 49.0 and 48.2). Related, a number of the NI-spreads (in price terms) display a wide range from negative to positive spreads. Spain and Italy, for example, have spreads at the 5% and 95% tail ranging from -75.2 and -126.0 to 51.1 and 75.0 basis points, while the U.S range is much tighter from 4.9 to 61.7 basis points. Moreover, the NI-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 0.89, 0.70, 0.44 and 0.25.

B. The CDS Spread

As a market price for default, the sovereign CDS spread is a common measure of the "quality" of sovereign bonds. Table 3 provides summary statistics for the CDS spread of each of the countries over the 2006-2018 sample period. Three countries stand out as having high mean and variable CDS spreads, namely Belgium (respectively 67.1 and 72.9 basis points), Spain (136.0 and 130.5 basis points) and Italy (150.1 and 121.4 basis points). The other five countries vary between 21.3 and 51.1 for their average CDS spread and 14.8 to 49.3 for their basis point volatility. Like the NI-spreads above, the range over the sample period suggests periods of "low" and "high" credit quality. Belgium, Spain and Italy, for example, have spreads at the 5% and 95% tail ranging from 2.3, 2.8 and 8.5 basis points to 245.0, 400.6 and 443 basis points, while the U.S range is much tighter from 1.5 to 42.3 basis points. Most important for the analysis to come, these three countries' abnormal CDS (measured as current CDS minus its 2-year moving average) ranges respectively from -115.4 to 114.0, -173.3 to 166.6, and -142.2 to 186.7. As CDS moves towards the tails of these ranges (i.e., as credit quality changes), we would expect the greatest price pressure as investors move in or out of these sovereign bonds.

C. The New Issue and CDS Spread

Figure 1 graphs the NI-spread and abnormal CDS-spreads over the time period for all eight countries. With respect to Belgium, Italy and Spain, note that there is a considerably long period, from 2009 to 2013, in which the NI-spreads go negative. This period coincides with the Euro crisis and, in particular, the sovereign debt crisis of the Eurozone periphery. Of course, the spreads, by construction, have no exposure *per se* to credit risk, so the credit difficulties of Italy, Spain and Belgium must be proxying for other relevant market conditions.

There are two reasons why the negative NI-spreads are likely “real” values. First, these spreads persist for months, reducing the chances of being due to measurement error. Second, as Figure 1 illustrates (and confirmed more formally in the next section), these NI-spreads covary with abnormal CDS spreads of the country, providing an economic justification. In particular, while the increase in CDS spreads is very apparent during the emergence of the financial crisis in the Fall of 2008 through Spring of 2009, this behavior in CDS spreads pales in comparison with that of the Eurozone crisis, which stopped and started throughout the summer of 2010 through 2013. Figure 1 shows that Belgium, France, Italy and Spain were all engulfed during this period though the crisis lingered longer and more severe for Italy and Spain. Much of this CDS spread behavior appears to coincide with the underlying tightening behavior (and even negative magnitude) of the NI-spreads. As credit conditions improve beyond 2013, the NI-spreads widen and turn positive.

As an example of violations of the law of one price, researchers may have expected the NI-spreads to widen as credit conditions worsen and liquidity in the markets dries up. But we document the opposite result. The rest of the paper is devoted to better documenting and understanding this finding.

III. Sovereign Credit and the Law of One Price

While the NI-spread on average captures the positive spread between previously issued and newly issued bonds, a perusal of the NI-spread 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 NI-spread?

As a preview, we document that the changing credit quality of the sovereign bond is an important determinant of the NI-spread. This result is interesting because, by construction, the NI-spreads wash out any credit risk as they are effectively long and short the same bonds of the same sovereign.

Moreover, this variable supersedes other possibilities, such as a common component to the NI-spreads across countries and the credit quality of the sovereign bond relative to other sovereigns.

A typical measure of the quality of the sovereign is its credit default swap (CDS) spread. We relate the current level of the CDS spread of a country to a moving average of the past CDS spread as a measure of whether the sovereign's credit has deteriorated or not relative to a benchmark level. Thus, we define $\Delta CDS_{it} \equiv \left(CDS_{it} - \frac{1}{T}\sum_{k=1}^{T} CDS_{it-k} \right)$.[10] The basic idea is twofold: (i) marginal investors fly *from* an asset as its quality worsens, and (ii), to the extent trading immediacy and transaction costs are important, investors choose to do this by transacting in the most liquid security.

Our main regression model represents a pooled, time-series regression of eight countries' 10-year NI-spread over the period 2006-2018:

$$\mathrm{NI}_{it} = \alpha_i + \beta\left(\Delta CDS_{it}\right) + \varepsilon_{it} \qquad (1)$$

Regression equation (1) allows us to ask how much of the variation of the NI-spread both through time and across countries can be explained by the countries' changing credit quality. The coefficient on the quality factor is the same across countries as the quality factor itself varies across countries.

Table 4 provides results for regression equation (1). The columns labelled 1 and 2 in Table 4 document the results of the regression of NI_{it} on ΔCDS_{it} with and without country fixed effects. The three key findings from regression (1) are (i) the intercept is on average positive (albeit insignificant), implying a positive NI-spread, (ii) the R^2s are 10.6% (and 26.0% with fixed effects), and (iii) the coefficient of -0.23 (-0.22 with fixed effects) is statistically significant. The fact that the R^2 is higher for the fixed effect is expected given Table 1 documents cross-sectional variation in the NI-spread levels across countries. Importantly, the coefficient on ΔCDS_{it} does not change. The impact of changing credit quality is economically significant. If the CDS is 100 basis points above its recent (2-year) benchmark level, the NI-spread will be 22 to 23 basis points tighter. For some countries, like Germany and the U.S., with relatively low standard deviations of ΔCDS_{it}, the impact on the NI-

[10] The choice parameter is the length of the moving average. What length constitutes the current benchmark level is an open question. As a compromise between recent levels or the historical mean, we choose the past two years.

spread will be low. However, as shown in Table 1, ΔCDS_{it} of Belgium, Spain and Italy all had considerable variation over the sample period.

As an alternative to ΔCDS_{it}, consider $CDS_{it}^{XSD} \equiv \left(CDS_{it} - \frac{1}{M} \sum_{i}^{M} CDS_{it} \right)$ as a measure of the relative credit quality across the *M* countries. Note that this 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).[11] CDS_{it}^{XSD} represents the country-specific 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. Columns 3-4 of Table 4 document an analogous regression equation (1) using the quality variable, CDS_{it}^{XSD}. Without country fixed effects (column 3), the R^2 is 8.8% (and 23.9% with fixed effects) with the coefficient on CDS quality being negative and statistically significant. Indeed, the sign of the coefficient suggests that if a country's credit quality is relatively low, that is, $CDS_{it}^{XSD} > 0$, then its NI-spread will be lower. The coefficient, -0.32, is statistically significant, but also economically meaningful. It implies that for every 100 basis points of additional CDS premium the NI-spread will fall by 32 basis points.

Our two measures of credit quality, ΔCDS_{it} and CDS_{it}^{XSD}, are clearly not independent. Which if these measures best explain variation of the NI-spreads? To analyze this question, we regress the NI-spreads on both ΔCDS_{it} and CDS_{it}^{XSD}:

$$\mathrm{NI}_{it} = \alpha_i + \beta_1 \left(\Delta CDS_{it} \right) + \beta_2 \left(CDS_{it}^{XSD} \right) + \varepsilon_{it} \tag{2}$$

The results are provided in columns 5 and 6 of Table 4. The R^2 jumps only slightly from 10.6% for ΔCDS_{it} and 8.8% for CDS_{it}^{XSD} to 11.76% for both measures. Clearly, these measures capture similar phenomena as the coefficients drop from -0.23 to -0.17 for ΔCDS_{it} and -0.32 to -0.16 for ΔCDS_{it}; however, the coefficient estimator on ΔCDS_{it} is still strongly significant whereas this is not the case

[11] 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 decompose 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.

for CDS_{it}^{XSD}. From an economic viewpoint, this result suggests that the dominating factor is more so a country's CDS relative to its benchmark than relative to other countries. In other words, a higher CDS in Italy relative to Germany does not mean a tighter NI-spread per se.

Ex ante, a strong candidate variable for explaining the variation of NI-spreads is a measure of "flight to liquidity" (in which all NI-spreads move together). To investigate this common factor, we construct the variable $F_t = \frac{1}{M}\sum_{i=1}^{M} NI_{it}$. Due to there being so few countries in the cross-section, for each individual NI-spread, we omit its own NI-spread from the factor F_t. Because the common factor, F_t, is almost the same across assets, we allow for a different coefficient estimator for each NI-spread. We run the regression: $\mathrm{NI}_{it} = \alpha_i + \beta_i \left(F_t^{\neq i} \right) + \varepsilon_{it}$.

Columns 7 and 8 of Table 4 report the results for this regression. The R^2 of the regression is essentially zero. None of the coefficient estimators are statistically significant and the signs vary widely across the NI-spreads – ex ante, one might have expected a positive loading. The novel finding is that a common liquidity factor provides no explanatory power for the NI-spreads. Not reported in the table, we also ran the results from regression (1) with both this common liquidity factor and ΔCDS_{it} in case an omitted variable drives these results. The coefficient on ΔCDS_{it} does not change and the R^2s do not increase, providing some additional evidence on the lack of a common liquidity factor.

In order to dig deeper into this finding, Table 5 provides the unconditional correlation matrix of both the NI-spreads and the residuals from regression (1) using ΔCDS_{it} over the 8 countries. Consider first the NI-spreads' correlation matrix. There is surprisingly little correlation across the NI-spreads. If there is a common liquidity factor, it is either small or offset by other factors. For example, focusing on just the seven European countries, in terms of absolute value of the correlation magnitude across all pairwise correlations, the average absolute correlation is just 17.0%. To the extent there are economically significant correlations, these correlations suggest an interesting pattern. For example, the Germany NI-spread tends to be negatively correlated with other countries in Europe (such as Belgium, Spain, France and Italy), yet positive with the U.S. At first glance, this seems surprising as one might expect that European counties would be subject to a more common liquidity factor. Indeed, the NI-spreads of Belgium, Spain, France and Italy are all positively correlated with an average level of 23.5%. Of course, this positive correlation is likely due to correlation across countries' deteriorating credit quality, and therefore captured by ΔCDS_{it}.

In order to investigate this possibility, consider the correlation matrix of the residuals from regression equation (1). Once ΔCDS_{it} has been taken into account, the positive correlations of the four countries drops to an average level of 7.7%. More generally, the average absolute correlation across the NI-spread residuals for the European countries drops from the aforementioned 17.0% to 13.3% with only 5 of the 21 pairs increasing in magnitude. Interestingly, the one exception to these correlation patterns are with respect to U.S. NI-spread residuals, which turn positive and tend to increase relative to their correlation to U.S. NI-spread levels.

IV. Why Is the Law of One Price Violated?

The NI-spreads vary and, most important, systematically through time. Measurement error aside, because the bonds have (i) matched cash flows and maturity, and (ii) the exact same credit risk, any nonzero NI-spread in theory represents a violation of the law of one price. The time-varying behavior of the NI-spread depends on a country's sovereign credit spread relative to its benchmark level (as measure by the recent past). Interestingly, this behavior is counter to typical models of liquidity which would suggest a widening, not a tightening, of this spread. What are possible explanations for the NI-spread behavior?

A. Price Pressure

Our preferred explanation is that, during stressful periods for sovereign credit, investors transact in the most liquid securities available and try and sell out of their holdings possibly for institutional reasons, i.e., "flight to quality". Price pressure then pushes down the price of the most liquid securities in decreasing credit quality countries as investors reallocate their asset holdings. Why do the prices of liquid sovereigns, however, fall so much relative to their illiquid counterpart?

To minimize transactions costs and price impact, suppose active investors (such as asset managers subject to outflows) select more liquid securities than the typical buy-and-hold investor. Further assume that liquid and illiquid bond markets are somewhat segmented and difficult to arbitrage across due to, for example, short-sale restrictions.[12] Without any limits to arbitrage, the prices of liquid and illiquid bonds should move in unison albeit with much heavier volume of the liquid bond. With market segmentation, however, once selling pressure pushes down the price of the newly issued bond, the previously issued bond does not have to follow suit. The natural arbitrage here would be to buy the cheaper newly issued bond and short the more expensive older bond, but this is difficult to implement due to illiquid bonds being more difficult to short. Prices can therefore diverge in segmented markets with heterogeneous investors (e.g., Boudoukh and Whitelaw (1993)).[13]

This theory leads to two additional implications that deserve scrutiny. If price pressure can explain the NI-spread, then we should expect to see that, (i) in times of decreasing sovereign credit quality, there should be capital outflows by "marginal" investors, and (ii) during price pressure episodes, shocks to the NI-spread should be temporary and be driven by newly issued, rather than previously issued bonds.

In order to proxy for net trading flows, we use State Street Associates' dataset on the aggregated activity of institutional investors. This measure, net flows into and out of sovereign government bonds, serves as our measure for buying and selling pressure. 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 primarily of large global institutional investors, including mutual funds, pensions, foundations and endowments.[14] 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

[12] See, for example, Buraschi, Sener and Mengauturk (2010) and Fontana and Scheicher (2016) for an analysis of shorting costs in the sovereign bond market.
[13] See also Harrison and Kreps (1978), Ofek and Richardson (2003), and Hong and Stein (2003).
[14] Who is on the other side of the transaction is an interesting question. At least in the recent financial crisis, there is some evidence that net sellers were institutional investors and net purchasers were domestic banks and central banks (e.g., Arslanalp and Poghosyyan (2014) and Arslanalp and Tsuda (2014)). The argument relies on institutional investors moving prices through selling pressure. The argument is complicated by the fact that the supply of government bonds is changing through time, so not all net flows are driven by demand shocks.

these transactions.[15] 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 (denote NF_{it} the normalized flows of country *i* at time *t*).

Table 6A documents the contemporaneous correlation pattern between 1,3 and 6 month accumulation of *CDS* changes, ΔCDS_{it} and corresponding accumulations of net flows, NF_{it}, from January 2006 to June 2018. The correlations of changes in the sovereign's quality with investor net flows are negative for almost all of the 8 countries (France being the exception albeit with effectively zero correlation). In other words, when the credit quality of a country worsens, there is an *increase in net flows out* of that country's sovereign bonds, i.e., a "flight to quality". Moreover, the magnitude of the correlation tends to increase with the horizon, consistent with noise in the net flows data. Of some note, the most negative correlations belong to the Euro countries that struggled during the recent crisis, namely Belgium (-0.10, -0.22, and -0.33), Spain (-0.19, -0.30 and -0.46), and Italy (-0.22, -0.37 and -0.53) at the monthly, quarterly and semi-annual horizon respectively. These countries suffered large negative shocks to their CDS premiums during the Euro crisis and exhibited negative NI-spreads during this same period (see Figures 1 and 2). It is interesting to note that this correlation pattern is between investor flows and CDS spreads, and does not involve the relative pricing of "identical" bonds per se.

Because much of our analysis focuses on ΔCDS_{it}, we run a pooled, time-series regression of ΔCDS_{it} on net flows NF_{it}. Since net flows are a measure of change in sovereign bonds holdings over a five-day period, in order to capture a level effect, we integrate over a sovereign bond's net flows using the prior and post 6 weeks around a given time period, yielding a quarterly average of net flows at any point in time. Net flows are thus transformed to a stock variable more in line with a level variable like CDS (albeit relative to a moving average). In Table 5B, we report regression results for the level of the CDS relative quality variable on the integrated net flows and contemporaneous net flow

[15] See Froot, O'Connell and Seasholes (2001) and Froot, Bhargava, Cuipa and Arabadjis (2014) for more detail on this dataset.

variable of sovereign bonds from the State Street data. The coefficients are all negative and strongly statistically significant. Therefore, consistent with the negative correlation between net flows and CDS documented in Table 5, Table 5B also shows that a transformed version of these variables is also negatively related.

While a contemporaneous negative correlation pattern between credit quality and institutional net flows of sovereign government bonds is consistent with the price pressure hypothesis, we should also expect to see large movements in NI-spreads around the price pressure periods, only to subside and revert once the price pressure is over. To investigate this possibility, we performed the following event study. Recall the credit variable, $\Delta CDS_{it} \equiv \left(CDS_{it} - \frac{1}{T}\sum_{k=1}^{T} CDS_{it-k} \right)$, measures how the current sovereign CDS level compares to the last two years of CDS levels. Here, looking back over the past expanding sample period (with a minimum of 52 weeks), we define credit events as the 3% largest ΔCDS_{it} throughout the sample. We define an event period as the initiation of this credit event and the following 13 weeks (i.e., 1 quarter), and only consider nonoverlapping event periods. Across the eight sovereigns, this led to 85 events. We break these 85 events into 5 buckets based on the CDS level (i.e., credit quality) of the sovereign at the event time, leading to 17 events. Figure 2 graphs the average NI-spread across the 17 events (relative to event day -1) over weeks -5 to +13 for high and low CDS sovereigns.

Figure 2 effectively illustrates the price pressure on the spread between newly and previously issued bonds of same maturity for low credit quality versus high credit quality sovereigns. Prior to the credit event (3% trigger for ΔCDS_{it}), the NI-spreads (relative to day -1) are fairly flat for both high and low CDS countries. Once the event is triggered, there is a rapid and large tightening of NI-spreads for high CDS sovereigns, dropping on average 25 basis points, all occurring within the first week subsequent to the event. By the third week, there is a slow reversion back to the initial level which takes a total of 10 weeks. In terms of a controlled comparison, note there is almost no effect for low CDS (high quality) countries as investors are not flying away from them even with some move in their credit quality. Figure 2 is broadly consistent with the notion that, during extreme periods of relative moves in a sovereign's credit quality, it takes a while for NI-spreads to revert to "normal" levels. This behavior is consistent with price pressure, that is, a rapid albeit temporary move in prices with a rebound as the pressure subsides.

B. Alternative Explanations

One alternative explanation of the behavior of the NI-spreads could in theory be stale pricing of the older bonds. When credit quality of a country deteriorates and investors move out of the country's government bonds, the NI-spread can fall or even turn negative if the prices of the newly issued bonds fall and, due to staleness, there is no corresponding move in the previously issued bonds.

On the surface, there are two reasons why staleness is unlikely to be a plausible explanation for the behavior of NI-spreads. First, the NI-spreads and country credit quality are persistent over several months. For example, the autocorrelation of NI-spreads range from 0.85 to 0.94 at 1 week, 0.53 to 0.86 at 1 month, and 0.23 to 0.69 quarterly (see Table 1). Idiosyncratic CDS spreads persist even more, ranging from 0.97 to 0.99 at 1 week, 0.87 to 0.95 at 1 month, and 0.72 to 0.84 quarterly (see Table 3). In contrast, staleness would induce mean-reversion over relatively short horizons.

Second, staleness in the older bond prices should show up as a lead-lag relation, with the newly issued bonds leading the older bonds but not vice versa. Table 7 documents the weekly autocorrelation and cross-autocorrelations of changes in the prices of the newly issued and its hypothetical older counterpart. There is no evidence of staleness of the older bond relative to newly issued series. The cross-autocorrelation between lagged new bond prices changes and current old bond price changes are actually negative (albeit small, -7.2%) for all of the 8 countries, the opposite of what staleness would imply. There is some slight evidence of negative autocorrelation of yield changes for both newly issued and older 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). Moreover, while the autocorrelations are quite similar for both the new and old bonds, the new bond has a more negative autocorrelation in 4 of 9 cases, equal in 3 cases and less negative in only one case. If anything, this finding suggests that the time-series properties of the NI-spread are more likely driven by the newly issued bond.

Are there other possible determinants of the NI-spread? One possibility are differences in characteristics between the newly versus previously issued bond. Three particular characteristics that have received interest in the literature are issuance size (e.g., D'Amico and King (2013), Greenwood and Vayanos (2014) and Lou, Yan and Zhang (2013)), intrinsic demand for the bond issue such as cheapest-to-deliver (CTD) or the bond's specialness (e.g., Krishnamurthy (2002) and Vayanos and Weill (2008)).

With respect to size, evidence of supply side effects and issuance size have documented price effects. Thus, variation in issuance size over the sample period could produce different prices of liquid and illiquid bonds. In terms of the CTD option and whether the most recently issued or a previously issued bond are likely to be deliverable into futures contracts, Ejsing and Sihvonen (2009) find that in Germany the older bonds are often more tied to the bond futures and thus more liquid. This potentially reverses the NI-spread. With respect to a bond's specialness (e.g., Krishnamurthi (2002), Vayanos and Weill (2008), Graveline and McBrady (2011), Banerjee and Graveline (2013), Fontana and Scheicher (2016) and Corradin and Maddaloni (2017)), the NI-spread may simply reflect the higher shorting demand for the newly issued bond, leading to a spread between the general repo rate and the repo rate on that bond. Indeed, these authors document periods in which the liquidity premium, as measured by the NI-spread, can be explained by shorting costs as opposed to differences in liquidity. Thus, a decrease (increase) in the overall specialness of the liquid bond of the weak (strong) sovereigns during a crisis could potentially explain the findings of Tables 4 through ΔCDS_{it} proxying for specialness. The existing literature if anything suggests the opposite. For the Italian bond market, both Fontana and Scheicher (2016) and Corradin and Maddaloni (2017) document increasing specialness during the Euro crisis. At first glance, bond specialness therefore does not seem to be the source underlying the "flight to quality" factor documented in this paper.

Nevertheless, columns 1-4 of Table 8 document the impact of all three of these characteristics on the NI-spreads. In particular, columns 3 and 4 include ΔCDS_{it} as a covariate but also control for these other three possibilities, namely, the relative issuance size of the new bond (size of the new issue minus that of the old one divided by their sum); a dummy variable equal to +1 if the newly issued bond is cheapest-to-deliver (CTD), -1 if the previously issued bond is CTD, and zero otherwise; and, as a measure of specialness, the difference of the borrowing cost of short-selling the newly issued versus previously issued bond (as reported by *Data Explorers* (Markit), e.g., Fontana and Scheicher (2016)). Table 8 finds that, in contrast to the supply side story, the coefficients are actually positive albeit insignificant. Greater issuance size for the newly issued bond increases the NI-spreads, consistent with larger issues having higher prices. With respect to CTD, due to its relation to the highly liquid futures contract, CTD issues may have greater liquidity, all else equal. Table 8 documents, however, a negative coefficient (again insignificant) which is inconsistent with a liquidity effect, but may suggest unique pricing of CTD issues. The specialness measure, however, is in the direction of the theory (again marginally insignificant). Specialness, as measured by lower funding cost for the newly issued bond, implies a higher NI-spread. In any event, none of the characteristic variables add much to the R^2 of the pooled regression of equation (1) in an economically meaningful way, suggesting these controls are second order to ΔCDS_{it}. And, more important, the coefficient and t-statistic of our "flight to quality" factor barely change, i.e., respectively from -0.23 to -0.23 and -4.83 to -4.93.

V. Conclusion

During "flight to quality" episodes, current theory implies investors "fly towards liquidity" with the NI-spread widening (e.g., Vayanos (2004)). There is some empirical support for the existence of this link in a variety of markets, including the U.S. Treasury bond market (Goyenko, Subrahmanyam and Ukhov (2011) and Longstaff (2004)), and the Euro-area government bond markets (Beber, Brandt, and Kavajecz (2009)). For example, Beber, Brandt, and Kavajecz (2009) document that even though spreads of sovereign bonds against the Euro-swap benchmark are primarily driven by credit quality of the sovereign, liquidity plays an important pricing role during times of high uncertainty. Darbha and Dufour (2015) and Pelizzon, Subrahmanyam, Tomio and Uno (2015) also document a relationship between credit quality and liquidity.

In this paper we show that NI-spreads of weak sovereigns behave contrary to this view. During periods of "flight to quality", investors shift from away from weak sovereign bonds. Investors use liquid bond issues to sell out of the low quality sovereigns precisely because they can transact larger amounts quickly, leading to price pressure on these bonds. Thus, when a country suffers credit deterioration, bond spreads tighten. In other words, the liquid bonds become cheaper, not more expensive, than their less liquid counterparts. This finding suggests segmentation of sovereign bond markets which do not allow costless arbitrage between newly and previously issued 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 additional, 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. We leave this topic, and related ones on an asset quality-based liquidity factor, to future research.

A. Appendix - The Issuance Cycle

Since most reissuances of sovereign government bonds are simply those of the existing most recently issued bond, the reissuance itself generally does not alter our identification of the most liquid newly issued bond. In instances where this is not the case, i.e., the reissuance is not of the most recently issued bond, we have to take into consideration the quantity that was issued. Intuitively, a small re-opening does not make a bond the most liquid one, while a large one does. We define "large" to be a reissuance of 70% or more of the original amount issued when the bond was first auctioned. The results largely are robust to this choice. We classify a bond with remaining time-to-maturity between 8.5 and 11.5 years to be part of the 10 year bond cohort. In order to determine the appropriate cohort, we consider the remaining time-to-maturity at the last point in time that the bond was reissued as its tenor. For all ten government issuers, we are able to identify the 10-year newly issued bond for the entire sample period.

Table A1A documents properties of the issuance cycle for the 10-year newly issued bond over the January 2006 to June 2018 period. The number of newly issued 10-year bonds range from a low of 15 for Netherlands to a high of 52 for the U.S. Related, the average issuance cycle is 355 days for Netherlands bonds while just 91 days for U.S. bonds. As mentioned above, rather than issuing a new bond, some countries simply reissue an existing bond. Table A1B documents the properties of the reissuance cycle. For 7 of the 8 countries in our sample, a majority of a country's bond reissuance occurs within 6 months. As an illustration, consider Italy. Italy issues 25% of the total issuance of a bond at initiation, then cumulative 38% up to 1 month after issuance, 63% up to 3 months, 90% up to 6 months and 93% up to 9 months. More generally, across the eight countries, the average (median) total issuance at 3, 6 and 9 months respectively is 60% (57%), 77% (75%) and 85% (85%). Table A1B confirms the assertion above that most reissuances are simply those of the existing most recently issued bond. Moreover, Table A1B shows that, 6 months after a new issue, governments tend to issue a new bond, thus starting the cycle over. Table A1B shows that, other than the U.K., this characteristic holds across all sovereign bond issuance.

Table A1 – Issuance Analysis

Table A1 documents properties of the issuance cycle for the 10-year newly issued bond across 7 developed European countries and the United States over the period January 2006 – December 2018. The represented countries are BE (Belgium), DE (Germany), ES (Spain), FR (France), GB (United Kingdom), IT (Italy), NL (Netherlands) and US (United States). Table A1A documents properties of the issuance cycle for the 10-year bond, while Table A1B documents the properties of the reissuance cycle.

Table A1A: 10-year Bond Issuance Cycle

	BE	DE	ES	FR	GB	IT	NL	US
Total Number	17	31	22	30	28	30	15	52
Average Issuance Cycle	313	152	225	167	176	161	355	91
Min Issuance Cycle	24	91	112	8	8	9	224	87
Max Issuance Cycle	371	196	487	270	490	305	406	94
STD Issuance Cycle	122	33	104	76	158	63	47	2
First Date	2-Jan-06	2-Jan-06	2-Jan-06	2-Jan-06	2-Jan-06	2-Jan-06	2-Jan-06	2-Jan-06

Table A1B: % of Total Amount Issued of 10-yr

	BE	DE	ES	FR	GB	IT	NL	US
< 0	0%	0%	0%	2%	0%	2%	0%	0%
First Issuance	33%	28%	33%	16%	10%	25%	42%	100%
Within 30D	34%	40%	39%	25%	14%	38%	42%	100%
Within 91D	49%	87%	56%	40%	25%	63%	57%	100%
Within 183D	66%	100%	77%	61%	46%	90%	73%	100%
Within 274D	84%	100%	81%	69%	63%	93%	86%	100%
Within 365D	95%	100%	84%	70%	71%	94%	90%	100%
Beyond 365D	5%	0%	16%	30%	29%	6%	10%	0%

References

Amihud, Yakov and Haim Mendelson, 1986, Asset pricing and the bid-ask spread, *Journal of Financial Economics* 17, 223-249.

Amihud, Yakov and Haim Mendelson, 1991, Liquidity, maturity and the yields on U.S. government securities, *Journal of Finance* 46, 1411-1426.

Arslanalp, Serkan and Tigran Poghosyyan, 2014, Foreign Investor Flows and Sovereign Bond Yields in Advanced Economies, IMF working paper 14/27.

Arslanalp, Serkan and Takahiro Tsuda, 2014, Tracking Global Demand for Advanced Economy Sovereign Debt, *IMF Economic Review* 62: 430-464.

Bai, J., Julliard, C., and Yuan, K., 2012, Eurozone Sovereign Bond Crisis: Liquidity or Fundamental Contagion, Working Paper.

Banerjee, Snehal, and Jeremy Graveline, 2013, The Cost of Short-Selling Liquid Securities, *Journal of Finance*, 68 (2): 637-664.

Beber, Alessandro, Michael W. Brandt and Kenneth A. Kavajecz, 2009, Flight-to-Quality or Flight-to-Liquidity? Evidence from the Euro-Area Bond Market. *The Review of Financial Studies* 22(3), 925-957.

Beetsma, Roel, Massimo Giuliodori, Jesper Hanson, and Frank De Jong, 2018,Cross-Border Auction Cycle Effects of Sovereign Bond Issuance in the Euro Area *Journal of Money, Credit and Banking* 50, no. 7: 1401-1440.

Ben-David, Itzhak, Francesco Franzoni, and Rabih Moussawi, 2012, Hedge fund stock trading in the financial crisis of 2007–2009. *The Review of Financial Studies* 25, no. 1: 1-54.

Boudoukh, Jacob, and Robert F. Whitelaw, 1993, Liquidity as a choice variable: A lesson from the Japanese government bond market, *The Review of Financial Studies* 6, 265-292.

Buraschi, Andrea, Emrah Sener, and Murat Meng¨ut¨urk, 2010, The Dynamics of Limits to Arbitrage: An Empirical Investigation of the Sovereign Bond Market, Working paper, Imperial College.

Cai, Fang, Song Han, Dan Li, and Yi Li, 2019, Institutional herding and its price impact: Evidence from the corporate bond market. *Journal of Financial Economics* 131, no. 1: 139-167.

Cornell, Bradford, and Alan C. Shapiro, 1990, The Mispricing of U.S. Treasury Bonds: A Case Study, *Review of Financial Studies* 2, 297-310.

Corradin, Stefano, and Angela Maddaloni, 2017, "The importance of being special: repo markets during the crisis," ECB working paper.

D'Amico, Stefania and Thomas B. King, 2013, "Flow and Stock Effects of Large-Scale Treasury Purchases: Evidence on the Importance of Local Supply," *Journal of Financial Economics,* 108, 425-448.

Darbha, M. and Dufour, A., 2015, Euro Area Government Bond Market liquidity, Working Paper, University of Reading.

Duffie, Darrell, Nicolae Garleanu and Lasse H. Pedersen, 2002, Securities lending, shorting, and pricing, *Journal of Financial Economics* 66, 307-339.

Edwin J. Elton and T. Clifton Green, 1998, Tax and liquidity effects in pricing of government bonds, *Journal of Finance* 53, 1533-62

Ejsing, Jacob, and Jukka Sihvonen, 2009, Liquidity premia in German government bonds, ECB working paper 1081.

Ellul, Andrew, Chotibhak Jotikasthira, and Christian T. Lundblad, 2011, Regulatory pressure and fire sales in the corporate bond market. *Journal of Financial Economics* 101, no. 3: 596-620.

Favero, Carlo, Marco Pagano, and Ernst-Ludwig Von Thadden. 2010. How Does Liquidity Affect Government Bond Yields? *Journal of Financial and Quantitative Analysis* 45 (1): 107-134.

Feldhutter, Peter. 2012. The same bond at different prices: identifying search frictions and selling pressures." *Review of Financial Studies* 25:1155-1206.

Fisher, Lawrence, and Roman L. Weil. 1971. "Coping with the risk of interest-rate fluctuations: returns to bondholders from naive and optimal strategies." *The Journal of Business* 44 (4): 408-431.

Fleming, Michael J., 2002, Are Larger Issues More Liquid? Evidence from Bill Reopenings, *Journal of Money, Credit and Banking* 34 (3): 707-735.

Fontana, Alessandro, and Martin Scheicher, 2016, "An analysis of euro area sovereign CDS and their relation with government bonds." *Journal of Banking & Finance* 62: 126-140.

Froot, Kenneth A., Bhargava, Rajeev, Cuipa, Edward S. and John S. Arabadjis, 2014, Multi-Asset Sentiment and Institutional Investor Behavior: A Cross-Asset Perspective, *Journal of Portfolio Management*, 144-156.

Froot, Kenneth A., Paul G.J. O'Connell and Mark S. Seasholes, 2001, The Portfolio Flows of International Investors, *Journal of Financial Economics* 59 (2): 151-193.

Goldreich, David, Bernd Hanke and Purnendu Nath, 2005, The price of future liquidity: Time-varying liquidity in the U.S. Treasury market, *Review of Finance* 9:1–32.

Goyenko, Ruslan, Avanidhar Subrahmanyam and Andrey Ukhov, 2011, The term structure of bond market liquidity and its implications for expected bond returns. *Journal of Financial and Quantitative Analysis*, *46*(1), 111-139.

Graveline, Jeremy J. and Matthew R. McBrady, 2011, Whom Makes On-the-run Treasuries Special?, *Journal of Financial Intermediation* 20 (4): 620-632.

Greenwood, Robin, and Dimitri Vayanos, 2010, "Price Pressure in the Government Bond Market," American Economic Review, Papers and Proceedings, 585-590.

Greenwood, Robin, and Dimitri Vayanos. 2014, Bond supply and excess bond returns. *The Review of Financial Studies* 27, no. 3: 663-713.

Grossman, Sanford J. and Merton H. Miller, 1988, Liquidity and market structure, *Journal of Finance* 43, 617-633.

Harrison, J. Michael and David M. Kreps, 1978, Speculative Investor Behavior in a Stock Market with Heterogenous Expectations, *The Quarterly Journal of Economics*, 92 (2): 323-336.

Hong, Harrison and Jeremy Stein, 2003, Differences of Opinion, Short-Sales Constraints, and Market Crashes, *The Review of Financial Studies*, 16 (2): 487-525.

Jiang, Hao, Dan Li, and Ashley Wang, 2017, Dynamic liquidity management by corporate bond mutual funds. *Available at SSRN 2776829* (2017).

Jordan, Bradford, Randy Jorgensen, and David Kuipers, 2000, The Relative Pricing of U.S. Treasury STRIPS, *Journal of Financial Economics* 56, 89-123.

Kamara, Avraham, 1994, Liquidity, taxes, and short-term treasury yields, *Journal of Financial and Quantitative Analysis* 29, 403-416.

Krishnamurthi, Arvind, 2002, The bond/old-bond spread, *Journal of financial Economics* 66, 463-506.

Longstaff, Francis A., 2004, The flight-to-liquidity premium in U.S. Treasury bond prices, *Journal of Business* 77 (3): 511-526.

Lou, Dong, Hongjun Yan and Zinfan Zhang, 2013, Anticipated and Repeated Shocks in Liquid Markets, *Review of Financial Studies* 26 (8): 1891-1912.

Manconi, Alberto, Massimo Massa, and Ayako Yasuda, 2012, The role of institutional investors in propagating the crisis of 2007–2008. *Journal of Financial Economics* 104, no. 3: 491-518.

Mitchell, Mark, Lasse Heje Pedersen, and Todd Pulvino, 2007, Slow moving capital. *American Economic Review* 97, no. 2: 215-220.

Ofek, Eli and Matthew Richardson, 2003, DotCom Mania: The Rise and Fall of Internet Stock Prices, *The Journal of Finance*, 58 (3): 1113-1138.

Pasquariello, Paolo and Clara Vega, 2009, The On-the-run *Liquidity* Phenomenon, *Journal of Financial Economics* 92 (1): 1-24.

Pelizzon, Loriana, Subrahmanyam, Marti G., Tomio, Davide and Jun Uno, 2015, Sovereign Credit Risk, Liquidity, and ECB Intervention: *Deus ex Machina*?, forthcoming *Journal of Financial Economics*.

Scholes, Myron S., 1972, The market for securities: Substitution versus price pressure and the effects of information on share prices. *Journal of business* 45, no. 2: 179.

Scholes, Myron, and Joseph Williams, 1977, Estimating betas from nonsynchronous data. *Journal of financial economics* 5, no. 3: 309-327.

Schwartz, Kyra, 2010, Mind the Gap: Disentangling Credit and Liquidity in Risk Spreads, working paper, The Wharton School, University of Pennsylvania.

Vayanos, Dimitri, 2004, Flight to quality, flight to liquidity and the pricing of risk, Working paper, LSE.

Vayanos, Dimitri, and Pierre-Oliver Weill, 2008, A Search-Based Theory of the On-the-Run Phenomenon, *Journal of Finance* 63, 1361-1398.
Vayanos, Dimitri, and Jean-Luc Vila. 2009. A preferred-habitat model of the term structure of interest rates." Working paper.

Warga, Arthur, 1992, Bond returns, liquidity, and missing data, *Journal of Financial and Quantitative Analysis* 27, 605-617.

Table 1 – Summary Statistics of NI-Spreads

Table 1 documents summary statistics for the NI-spread (the difference of prices between a hypothetical bond priced by the older bond curve minus its newly issued counterpart), for the 10-year bond across 7 developed European countries and the United States over the period January 2006 to June 2018. Also provided is the average naïve spread (the difference of prices between the newly issued bond and its most recently issued one). The represented countries are BE (Belgium), DE (Germany), ES (Spain), FR (France), GB (United Kingdom), IT (Italy), NL (Netherlands) and US (United States).

	BE	DE	ES	FR	GB	IT	NL	US	Average
# of Obs	652	652	652	652	652	652	651	652	652
Average Naïve Premium	-13.56	-4.53	-8.30	-8.40	-10.41	-8.84	-12.06	-0.99	-8.39
Average	-17.18	14.18	0.42	1.28	-10.62	-24.31	11.30	22.70	-0.28
	(-3.13)	(2.29)	(0.11)	(0.34)	(-2.19)	(-1.99)	(2.19)	(4.56)	-
STD	20.4	6.5	23.9	10.1	11.3	19.7	10.0	6.6	13.6
Daily Price Volatility	38.13	36.26	48.95	36.42	43.55	48.17	35.42	45.46	41.54
5th %	-108.0	-16.0	-75.2	-26.9	-45.8	-126.0	-19.0	4.9	-51.5
50th %	-13.1	11.7	3.5	0.7	-10.1	-19.9	9.2	18.7	0.1
95th %	34.4	47.8	51.1	34.0	17.2	75.0	40.1	61.7	45.1
rho(1)	0.90	0.94	0.88	0.85	0.85	0.94	0.86	0.92	0.89
rho(4)	0.66	0.86	0.67	0.68	0.53	0.83	0.69	0.73	0.70
rho(12)	0.44	0.69	0.25	0.35	0.23	0.58	0.46	0.53	0.44
rho(24)	0.30	0.57	0.06	0.03	-0.01	0.54	0.25	0.23	0.25

Table 2 – Yield Spreads and Maturity Mismatch

Table 2 documents summary statistics for the yield spread between the latest issued and likewise newly issued 10-year bond (denoted naïve spread), as well as the NI-spread, across 7 developed European countries and the United States over the period January 2006 to June 2018. The represented countries are BE (Belgium), DE (Germany), ES (Spain), FR (France), GB (United Kingdom), IT (Italy), NL (Netherlands) and US (United States). The NI-spread is the difference of yields between a hypothetical bond priced by the older bond' curve minus its newly issued counterpart, i.e., $NI - spread = y^{hyp} - y^{actual} = \frac{price^{hyp} - price^{actual}}{price^{hyp} \cdot duration}$. Table 2 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.

	Naïve Yield Spread			New Issue Spread		
	1	2	3	4	5	6
Local Slope	0.76		0.85	-0.15		-0.10
	(12.64)		(17.68)	(-3.13)		(-2.10)
Duration		-8.53	-11.56		-7.86	-7.50
		(-1.65)	(-3.58)		(-2.22)	(-2.16)
Convexity		0.96	0.56		0.34	0.38
		(2.58)	(2.45)		(1.49)	(1.67)
r2	66%	34%	68%	20%	21%	22%
r2 net of FE	59%	25%	62%	1%	3%	4%
# of Obs	5,215	5,215	5,215	5,215	5,215	5,215

Table 3 – CDS Spreads

Table 3 documents summary statistics for the CDS spread and relative CDS spread, $CDS_t - \sum_k^{2yrs} CDS_{t-k}$ across 7 developed European countries and the United States over the period January 2006 to June 2018. The represented countries are BE (Belgium), DE (Germany), ES (Spain), FR (France), GB (United Kingdom), IT (Italy), NL (Netherlands) and US (United States).

	BE	DE	ES	FR	GB	IT	NL	US	Average
# of Obs	652	652	652	652	640	652	652	652	651
Summary Statisitcs of CDS									
Average	67.11	27.02	135.98	51.13	38.53	150.11	34.13	21.32	65.67
STD	72.9	24.2	130.5	49.3	30.1	121.4	29.9	14.8	59.1
5th %	2.3	1.7	2.8	1.7	1.6	8.5	1.8	1.5	2.7
50th %	43.7	20.3	89.7	38.4	28.8	130.2	27.0	20.0	49.8
95th %	245.0	84.7	400.6	177.2	91.6	443.0	105.7	42.3	198.8
rho(1)	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.98	0.99
rho(4)	0.97	0.95	0.98	0.97	0.96	0.97	0.96	0.91	0.96
rho(12)	0.89	0.84	0.92	0.89	0.83	0.88	0.82	0.76	0.85
Summary Statisitcs of Relative CDS									
Average	1.39	0.77	4.53	1.66	1.80	10.10	1.02	1.31	2.82
STD	56.7	18.5	89.4	36.7	24.6	89.6	23.8	12.0	43.9
5th %	-115.4	-32.6	-173.3	-62.3	-24.3	-142.2	-28.8	-11.9	-73.9
50th %	-0.6	-0.7	0.0	-0.9	-3.4	2.7	-1.4	-0.1	-0.6
95th %	114.0	39.5	166.6	72.1	45.0	186.7	53.3	18.8	87.0
rho(1)	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.97	0.99
rho(4)	0.95	0.92	0.95	0.95	0.93	0.94	0.94	0.87	0.93
rho(12)	0.82	0.73	0.84	0.81	0.73	0.78	0.72	0.64	0.76

Table 4: NI-Spreads and Sovereign Credit

Table 4 documents the regression of the NI-spread (the difference of prices between a hypothetical bond priced by the older bond curve minus its newly issued counterpart), for the 10-year bond on (i) a measure of the sovereign's credit quality relative to its past, (ii) a measure of its relative credit quality versus other countries, and (iii) a common NI-spread factor. This regression is a pooled, time-series analysis across 7 developed European countries and the United States over the period January 2006 to June 2018 with and without fixed effects. The represented countries are BE (Belgium), DE (Germany), ES (Spain), FR (France), GB (United Kingdom), IT (Italy), NL (Netherlands) and US (United States). The definition of the measures (i)-(iii) above are respectively: $\Delta CDS_{it} \equiv \left(CDS_{it} - \frac{1}{T}\sum_{k=1}^{T} CDS_{it-k} \right)$, $CDS_{it}^{XSD} \equiv \left(CDS_{it} - \frac{1}{M}\sum_{i}^{M} CDS_{it} \right)$ and $F_t = \frac{1}{M}\sum_{i=1}^{M} NI_{it}$.

	1	2	3	4	5	6	7	8
Intercept	0.30	FE	-0.36	FE	0.11	FE	-0.37	FE
	(0.10)		(-0.12)		(0.04)		(-0.11)	
BE							-0.03	0.78
							(-0.06)	(1.68)
DE							-0.03	-0.04
							(-0.07)	(-0.15)
ES							0.05	0.04
							(0.09)	(0.08)
FR							-0.01	-0.05
							(-0.06)	(-0.37)
GB							-0.35	-0.11
							(-1.34)	(-0.52)
IT							0.38	1.67
							(0.35)	(2.21)
NL							0.02	0.01
							(0.06)	(0.04)
US							-0.17	0.01
							(-0.48)	(0.07)
ΔCDS	-0.23	-0.22			-0.17	-0.17		
	(-4.80)	(-5.45)			(-2.73)	(-3.46)		
CDS(XSD)			-0.32	-0.30	-0.16	-0.14		
			(-4.14)	(-4.69)	(-1.70)	(-2.00)		
r2	11%	26%	9%	24%	12%	27%	0%	20%
# of Obs	5,152	5,152	5,152	5,152	5,152	5,152	5,215	5,215

Table 5 – Correlation Between NI Spreads and Residual NI spreads

Table 5 documents the correlation matrix between the NI-spreads and residual NI-spreads (the difference of prices between a hypothetical bond priced by the older bond curve minus its newly issued counterpart) for the 10-year bond across 7 developed European countries and the United States over the period January 2006 to June 2018. The represented countries are BE (Belgium), DE (Germany), ES (Spain), FR (France), GB (United Kingdom), IT (Italy), NL (Netherlands) and US (United States). The top number represents the raw correlation and the bottom number the residual correlations. The residuals are estimated from a regression of the NI-spreads on each sovereigns' measure of its credit quality relative to its past, i.e., $\Delta CDS_{it} \equiv \left(CDS_{it} - \frac{1}{T}\sum_{k=1}^{T} CDS_{it-k} \right)$.

	BE	DE	ES	FR	GB	IT	NL	US
BE	1.00	-0.14	0.19	0.30	0.01	0.44	-0.20	-0.02
		-0.04	-0.01	0.15	0.03	0.32	-0.20	0.08
DE		1.00	-0.11	-0.24	0.18	-0.06	0.52	0.47
			0.06	-0.01	0.34	0.03	0.61	0.51
ES			1.00	0.03	-0.29	0.37	-0.07	-0.01
				-0.13	-0.23	0.20	0.03	0.13
FR				1.00	-0.09	0.08	-0.12	-0.16
					-0.02	-0.07	0.02	-0.06
GB					1.00	-0.06	0.05	0.08
						-0.09	0.19	0.24
IT						1.00	-0.02	-0.04
							-0.01	0.02
NL							1.00	0.13
								0.22
US								1.00

Table 6: Sovereign Credit and Net Flows of Sovereign Bonds

Table 6A documents the contemporaneous correlation pattern between a sovereigns' measure of its credit quality relative to its past, i.e., $\Delta CDS_{it} \equiv \left(CDS_{it} - \frac{1}{T}\sum_{k=1}^{T} CDS_{it-k} \right)$, and net flows of sovereign government bonds across 7 European developed countries and the United States from January 2006 to June 2018. The data on net flows is provided by State Street Corporation. For State Street data, 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 BE (Belgium), DE (Germany), ES (Spain), FR (France), GB (United Kingdom), IT (Italy), NL (Netherlands) and US (United States). The table reports the correlation pattern using the State Street data for 1-month, quarterly and semi-annual cumulative net flows and the cumulative ΔCDS quality measure. Table 6B reports a regression of ΔCDS_{it}against the net flows factor. Net flows are relative to a five-year history. We integrate them over the past and future 6 week period.

A. Correlation of and State Street Net Flows

	BE	DE	ES	FR	GB	IT	NL	US
1 Month	-0.09	-0.13	-0.18	0.01	-0.03	-0.29	-0.21	-0.07
3 Month	-0.17	-0.07	-0.22	-0.03	-0.07	-0.33	-0.32	-0.10
6 Month	-0.24	-0.08	-0.32	0.01	-0.03	-0.40	-0.29	-0.15

B. Sovereign Credit and Net Flows

	-6W to +6W	-6W to -1W	+1W to +6W	0W
ΔCDS x 100	-3.73	-1.97	-1.44	-0.33
	(-4.61)	(-5.10)	(-3.76)	(-4.95)
r2	10%	7%	5%	3%
# of Obs	5,058	5,058	5,058	5,058

Table 7: Price Staleness of Sovereign Bonds and Lead-Lag Relationship

Table 7 documents the autocorrelation (ρ_1) and cross-autocorrelation of changes in a hypothetical bond priced by the older bonds' curve and in its newly issued counterpart for the 10-year bond across 7 developed European countries and the United States over the period January 2006 to June 2018. The represented countries are BE (Belgium), DE (Germany), ES (Spain), FR (France), GB (United Kingdom), IT (Italy), NL (Netherlands) and US (United States).

	BE	DE	ES	FR	GB	IT	NL	US
New Bond ρ_1	-0.09	-0.06	-0.11	-0.06	-0.10	-0.10	-0.07	-0.08
Old Bond ρ_1	-0.08	-0.06	-0.07	-0.06	-0.09	-0.10	-0.08	-0.07
Difference	-0.01	0.01	-0.03	0.00	-0.01	0.00	0.00	0.00
	(-0.44)	(0.64)	(-1.66)	(0.14)	(-1.03)	(0.11)	(0.42)	(-0.44)
New Bond lead	-0.09	-0.06	-0.08	-0.05	-0.08	-0.09	-0.07	-0.07
Old Bond lead	-0.07	-0.05	-0.08	-0.06	-0.07	-0.10	-0.06	-0.07
Difference	-0.01	-0.01	0.00	0.02	-0.01	0.01	0.00	0.00
	(0.96)	(0.49)	(0.02)	(-1.61)	(0.68)	(-0.66)	(0.26)	(0.38)
# of Obs	651	651	651	651	651	651	648	651

Table 8 – Sovereign Credit or Bond Characteristics

Table 8 documents the regression of the NI-spread (the difference of prices between a hypothetical bond priced by the older bond curve minus its newly issued counterpart) for the 10-year bond on (i) a measure of the sovereign's credit quality relative to its past, $\Delta CDS_{it} \equiv \left(CDS_{it} - \frac{1}{T}\sum_{k=1}^{T} CDS_{it-k} \right)$, and (ii) specific bond characteristic variables, including the relative issuance size of the new bond (size of the new issue minus that of the old one divided by their sum), a dummy variable if the newly issued bond is cheapest-to-deliver (CTD) and a variable measuring specialness by taking the difference of the borrowing cost of short-selling the newly and previously bond. This regression is a pooled, time-series analysis across 7 developed European countries and the United States over the period January 2006 to June 2018 with and without fixed effects. The represented countries are BE (Belgium), DE (Germany), ES (Spain), FR (France), GB (United Kingdom), IT (Italy), NL (Netherlands) and US (United States).

	1	2	3	4
Intercept	0.13	FE	-0.60	FE
	(0.04)		(-0.19)	
ΔCDS	-0.23	-0.22	-0.23	-0.22
	(-4.83)	(-5.40)	(-4.93)	(-5.49)
CTD			-2.25	3.56
			(-0.42)	(0.76)
Issuance			9.74	10.12
			(0.99)	(1.33)
Specialness			3.05	1.95
			(1.82)	(1.26)
r2	10%	26%	11%	26%
# of Obs	4,864	4,864	4,864	4,864

FIGURE 1: Newly Issued Bond Spreads and Sovereign Credit

Figure 1 graphs the spread between a hypothetical bond priced by the older bonds' curve minus its newly issued counterpart over the period January 2006 to June 2018. The spreads are graphed with the sovereign CDS spread minus its 2-year moving average. The represented countries are BD (Germany), BG (Belgium), ES (Spain), FR (France), IT (Italy), NL (Netherlands), UK (United Kingdom) and US (United States).

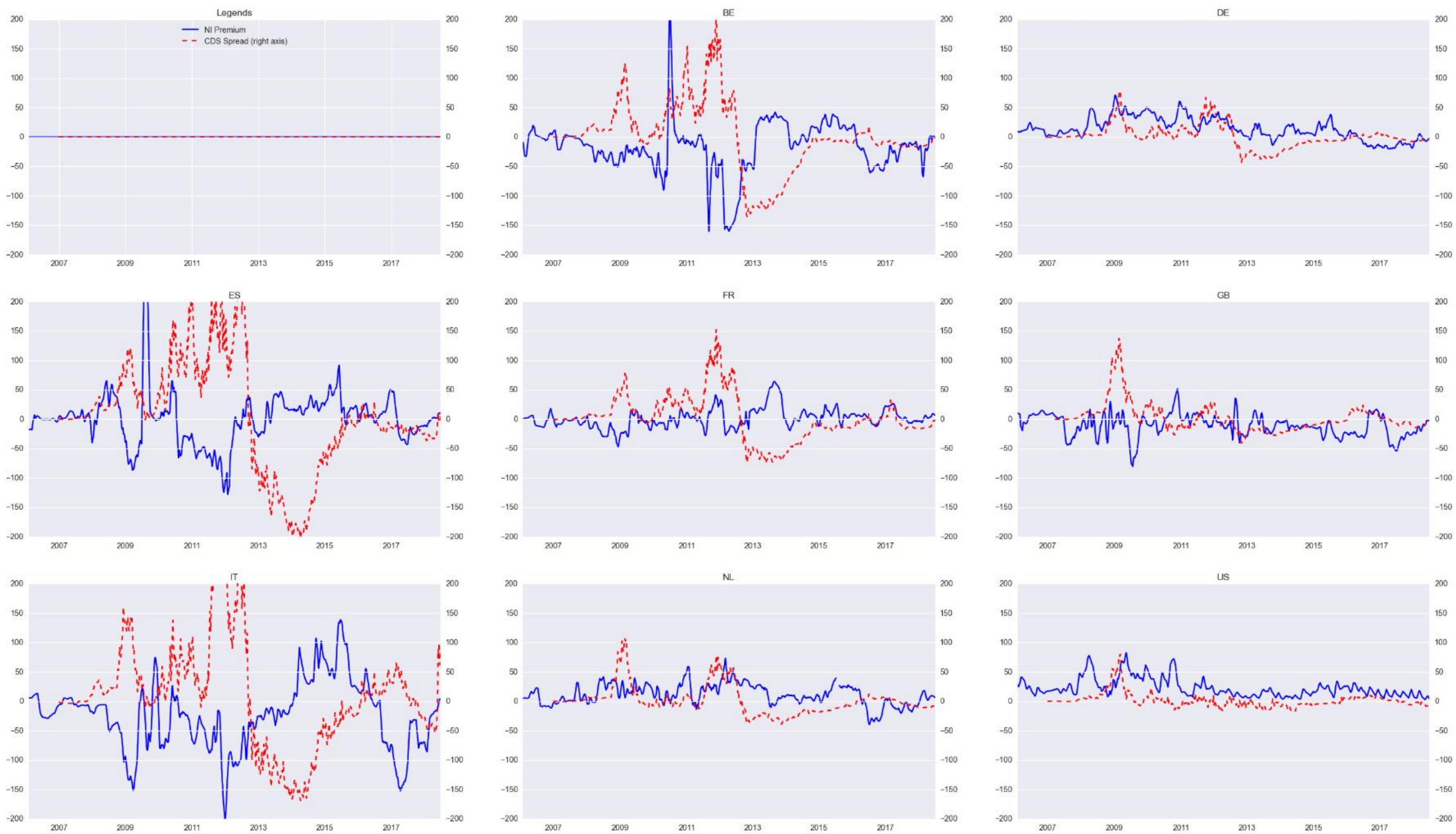

FIGURE 2: NI-spreads During Sovereign Credit Events

Figure 2 graphs the average NI-spread (the difference of prices between a hypothetical bond priced by the older bond curve minus its newly issued counterpart) (relative to event day -1) across extreme sovereign credit quality events over weeks -5 to +13 for high and low CDS sovereigns. The period covered is January 2006 to June 2018 for 7 European countries (Germany, Belgium, Spain, France, Italy, Netherlands and United Kingdom) and United States. The sovereign credit events are defined for each country as its 3% largest CDS spreads minus its 2-year moving average over the sample period. We define an event period as the initiation of this credit event and the following 13 weeks (i.e., 1 quarter), and only consider nonoverlapping event periods. These events are separated into 5 buckets based on the CDS level (i.e., credit quality) of the sovereign at the event time (denoted below as High Quality (in blue) and Low Quality (in red)).

Basis Points