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Dimensions of Limits to Arbitrage: Evidence from Coupon Spreads and Repo Specials in the 10-Year US Treasury Market

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A note's coupon spread is its price minus the price of a replicating portfolio of fungible coupon strips. We empirically examine limits of arbitrage in the US Treasury 10-year note complex over the period 1997 - 2011 with panels of coupon spreads and repo specialness on all notes. We find important systematic components in coupon spreads. The most important of these is a "level factor" that is positively correlated with Hu, Pan, and Wang's (2012) Noise measure. We show that the optical arbitrages during the financial crisis result from a non-fundamental supply shock since they are not anticipated by frictions prior to the crisis. Prior to the crisis coupon spreads are tightly linked to expected future repo specialness. This link is broken during the crisis, when we see concurrently historically high coupon spreads and low repo specials. Constraints on arbitrage capital not only allow large differences between the market prices of two identical streams of future cash flows to persist, they beget the price divergence in the first place. The Fed's announcement that its asset buying would extend to US Treasury notes and bonds in March 2009, induced a large, immediate, and permanent drop in coupon spreads.

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A note's coupon spread is its price minus the price of a replicating portfolio of fungible coupon strips. We empirically examine limits of arbitrage in the US Treasury 10-year note complex over the period 1997 - 2011 with panels of coupon spreads and repo specialness on all notes.[1] We first establish the distinction between optical arbitrage and tradeable arbitrage. As noted by Krishnamurthy (2002) and Nashikkar (2007), optical arbitrage is not the same as tradeable arbitrage once the effects of repo specialness are considered. In fact, prior to the the second half of 2008, coupon spreads in the 10-year Treasury note complex generally reflect expected future repo specialness. Before the crisis we show that whereas repo specialness is widespread and often anecdotal, positive coupon spreads are rarer and seen when the repo specialness is both expected, and expected to persist.

Recognizing this, a puzzling aspect of the financial crisis, which is evident in Figures 1 and 2, is that repo specialness falls to historically low levels (generally one basis point or less), while at the same time coupon spreads spike to historically high levels. The on-the-run premium provides additional evidence of a breakdown in the relationship between coupon spreads and expected future specialness during the crisis. Figures 1 and 2 show that in the late summer of 2003, the first off-the run note (maturing in May 2013) has a higher coupon spread than the on-the-run note (maturing in August 2013); i.e., the on-the-run premium was negative. This coincided with the May 2013 note also trading at higher and more persistent specialness than its successor. By contrast, there is also a negative on-the-run premium in late 2008, but there is no specialness on either note during this period.

The disconnect between coupon spreads and repo specials suggests that not only was arbitrage capital scarce in the crisis (which has been the focus of most of the empirical analysis of this episode), but the crisis coincided with important non-fundamental demand and supply shocks. Further evidence that the reason for the historically high coupon spreads is a non-fundamental supply shock and not simply a drop in arbitrage capital is provided by the ultimate convergence itself. The downward spike in coupon spreads that is evident in Figure 1 occurs on March 19, 2009– immediately after the Fed announced that it was extending its asset purchases (under its first round of quantitative easing) to Treasury bonds–before it purchased a single bond.

The conjunction between the factors that constrain arbitrage capital and actually beget trade-

[1] While a few studies have benchmarked Treasury securities to strips, there is no systematic study of coupon spreads per se in the literature. Grinblatt and Longstaff (2000) find that stripping activity is not related to apparent valuation deviations, instead they infer that stripping activity completes the market. Carayannopoulos (1995), Jordan, Jordan, and Kuipers (1998), Jordan, Jordan, and Jorgensen (1995), Jordan and Kuipers (1997), and Kuipers (2008) use strips to benchmark notes. Sack (2000) recommends using coupon strips to construct the yield curve, since they are highly liquid and devoid of idiosyncracies.

able arbitrage conditions is anticipated by Gromb and Vayanos (2010) who stress that tradeable arbitrage requires both a non-fundamental supply shock and frictions that restrict the activity of arbitrageurs. Furthermore they argue that both of these are intricately linked. "Many non-fundamental supply shocks can be understood jointly with limits of arbitrage within a setting that emphasizes financial institutions and agency," (Gromb and Vayanos 2010, p. 253). Gromb and Vayanos note that studying the limits of arbitrage is therefore couched within the broad framework of the relationship between financial institutions and agency frictions on the one hand, and asset prices on the other.

We document a flattening-out of the on-the-run premium in the decade leading up to the crisis, as both coupon spreads and repo specials become more homogeneous. This pattern is consistent with inflows of arbitrage capital–smoothing out the on-the-run premium. We document this using principal components analysis and factor analysis. This increase in risk capital is evident in Figure 3: both overnight repo positions in Treasuries and dealer (short) inventories increased three-fold over this period. We will not rely on the repo positions, as Krishnamurthy, Nagel, and Orlov (2012) and Copeland, Martin, and Walker (2012) provide reasons to take the size of inter-dealer repo with a grain of salt. This balance reflects dealer positions in the bilateral repo market–much of which involves rehypothecation. So it does not fairly reflect the use of repo to finance net asset positions.[2]

There is a non-fundamental supply shock in 2000, as discussed by Han, Longstaff, and Merrill (2007), when the US Treasury bought back some $67.5 billion in outstanding 30-year bonds between March 2000 and April 2002. Figure 1 shows that this had a disproportionate effect on the supply of strips, as the percentage of bonds held in stripped form dropped much more than the bond supply itself. Not surprisingly, and as also evident in Figure 1, coupon spreads on all notes fell during this period. There is a similar drop in the supply of strips in the midst of the crisis, but in this setting coupon spreads spike to historically high levels.

The large and persistent optical arbitrages that we document in this complex from November 2008 through March 2009, are not anticipated by any behavior during the decade preceding the crisis. A glance at Figure 1 shows the scope of price deviations. On December 12, 2008, the 4% February 2015 note had a coupon spread of 562.5¢, or 5% of its market price. This note is not deliverable against the futures contract, and is not more liquid (in terms of trading activity or

[2]Instead, both Krishnamurthy, Nagel, and Orlov (2012) and Copeland, Martin, and Walker (2012) note that tri-party repo, which is a measure of the flow of funds from outside of the shadow banking system into this system, remains fairly constant throughout the crisis.

bid-ask spread) than the coupon strips. The onset of the crisis therefore coincides with important non-fundamental supply shocks. The drop in dealer short positions through the crisis, which is evident in Figure 3, may proxy for this shock that both caused the spike in coupon spreads and allowed it to persist for several months during the crisis. On July 18, 2007 dealers were net short $56.9 billion in 6-11 year (nominal) Treasury notes and bonds. To put this amount in perspective, the May 15 (opening 10-year note) auction was for $17.6 billion. Figure 3 shows that dealers unwound their large short positions steadily– reaching a flat net inventory in February 2009. Long inventories peaked at $22 billion in May 2010.

We analyze the dimensionality of coupon spreads. We find that there are multiple drivers of the cross-section of coupon spreads. Furthermore, the relative importance of these components varies over time in ways that are consistent with institutional changes in the market. There are three natural subperiods in our data. The first principal component accounts for 43, 53, and 81% of total correlation in Periods 1 (1997 through 2002), 2 (2003 through June 2008), and 3 (July 2008 through March 2011), respectively. While this first factor is positively correlated with Hu, Pan, and Wang's (2012) noise measure in all three periods, this correlation increases from 31% in Period 1 to 83% in Period 2, and 94% in Period 3. There is a "slope factor" in the cross-section of coupon spreads in Period 1, that does not exist in later periods, which accounts for over 16% of the total correlation structure and is inversely correlated with the Hu, Pan, and Wang measure. In Period 1 especially, the second factor shows that more arbitrage capital can increase price heterogeneity (and coupon spreads) through the repo specialness channel.

We can reject the hypothesis that coupon spreads reflect differences between assets' transactional liquidity in the 10-year Treasury complex. Indeed, the reduction in the on-the-run premium in Period 2 occurs while institutional and technological changes increase the liquidity differential between this note and its predecessors. Barclay, Hendershott, and Kotz (2006) show that following the introduction of electronic platforms for trading in the on-the-run note, trading volume in an on-the-run note drops by 90% after it goes off-the-run. Mizrach and Neely (2006) and Fleming and Mizrach (2009) show that realized and quoted bid-ask spreads on eSpeed and BrokerTec (the electronic platforms for on-the-run notes) are materially lower than on GovPx–the voice platform used for off-the-runs and for on-the-runs prior to automation.

Gromb and Vayanos (2010) stress the importance of studying public policy aimed at changing the strength of financial institutions and/or modifying market frictions within the context of the limits to arbitrage. We have already noted the large impact that the Fed's announcement extending quantitative easing to US Treasuries had on coupon spreads. Another policy intervention directed at changing market frictions is the promulgation of a minimum delivery fails charge of 300 basis points for US Treasury securities on May 1, 2009, (Garbade, Keane, Logan, Stokes, and Wolgemuth 2010; and Gongloff and Zeng 2011). Delivery fails in the repo market reached record levels in the financial crisis. The fails penalty is designed to discourage delivery fails in repo, and presumably enhance the efficiency of repo financing and securities lending. We find evidence that repo specialness is higher after this regulatory intervention. This is evident in Figure 2, which shows that the average on-the-run note's specialness over the period October 1, 2008 - April 30, 2009 is 6 basis points (with a standard error of 0.7 basis points). This average between May 1, 2009 and July 31, 2009 is 77 basis points (with a standard error of 13.2 basis points). Figure 2 shows the negative of the first off-the-run note's specialness so that it can be contrasted with the on-the-run note's.

Examples of optical arbitrage at various stages in the financial crisis from other markets include Baba and Packer (2009) and Baba, Packer, and Nagano (2008), who show that covered interest parity between the US dollar and the euro was violated materially from August 2007 through September 2008. Baba, Packer, and Nagano argue that non-US financial institutions faced US dollar funding shortages which caused this unusual situation.[3]

Mitchell and Pulvino (2012) show that convertible bond arbitrage opened up as convertible bond prices fell significantly below their fundamental values. Bai and Collin-Dufresne (2010) and Mitchell and Pulvino (2012) demonstrate that spreads between corporate bonds and credit default swap spreads (the CDS-bond basis) widened, and Foley-Fisher (2010) shows the same optical arbitrage opened up in European sovereign debt. Mackenzie (2009) documents negative 30-year swap spreads throughout 2009. Supporting the hypothesis that such situations result from a contraction of risky balance sheets, he quotes Fidelio Tata of RBS Securities: " 'Very few investors can take advantage of the arbitrage between swaps and Treasuries, as you need a balance sheet to put on that trade, . . . The repo market is still dysfunctional and you need access to repo financing for a long period.' " Mitchell and Pulvino (2012) also find that during the period, September 19, 2008 through March 31, 2009, the CDS bond basis and the underpricing of convertible bonds–which are uncorrelated in normal times–had a 91% correlation. They infer that this is the result of both spreads being determined by the shortage of arbitrage capital during the crisis period. Buraschi, Sener, and Menguturk (2012) introduce an empirical measure of limits to arbitrage, based on the (currency) interest rate adjusted spreads on emerging market

[3]Griffoli and Ranaldo (2011) use currency-specific interbank repo rates to show that indeed a lack of dollar liquidity explains the documented departures from covered interest rate parity–taking advantage of the deviation required borrowing dollars.

countries' sovereign debt–issued in US dollars and euros. They show that this measure is close to zero before and after the crisis, but that during the financial crisis, which they date as September 2008 through March 2009, it increases in level and volatility.

The paper most similar to this is Fleckenstein, Longstaff, and Lustig (2013) who show that Treasury Inflation Protected Securities (TIPS) tend to trade at a discount to nominal bonds hedged to inflation using zero-coupon inflation swaps. They show that this discount widened appreciably during the financial crisis. They document that increased hedge fund inflows are correlated with a decline in the TIPS premium. Fleckenstein, Longstaff, and Lustig document that biases widened to up to fives times pre-crisis levels during the crisis. As with most of the other empirical analyses of optical arbitrages during the crisis, the implication is that abitrageurs' impact on markets is purely beneficial–enforcing the law of one price. By contrast, we find evidence of a non-fundamental supply shock propagated by the institutions making convergence trades. The 10-year Treasury complex is a useful prism through which to view the nature of the crisis for several reasons. First, the coupon spread is the price difference between two assets with identical future cash flows–a textbook arbitrage. Second, the arbitrage does not entail counterparty risk, such as exists with over-the-counter swaps. Third, as Sack (2000) and Mitchell and Pulvino (2012) note Treasury notes and strips are extremely liquid, and retained their liquidity in repo markets through the crisis. Fourth, we can relate coupon spreads to expected future specialness, and finally we have an entire yield curve of coupon spreads.

The remainder of this paper is structured as follows. We describe our data and review the institutional setting in Section I. We apply principal components analysis and factor analysis using data augmentation with the Gibbs sampler in Section II. Here we construct exact posteriors of the eigenvalues and eigenvectors to characterize the cross-sectional patterns in coupon spreads in each period. We examine the relationships between coupon spreads and repo specialness in Section III. We study public policy and limits to arbitrage in Section IV, isolating the introduction of the delivery fails penalty on May 1, 2009, and quantitative easing. Section V concludes the paper. We provide technical details about our data, the role of the Fed in securities lending and the mechanics of the Fed's quantitative easing program, the Gibbs sampler used in principal components analysis, and the estimation of factor models (also using the Gibbs sampler), in four appendices.

I. Data and Institutions

A. Coupon Spreads

Appendix A provides details on the data. We define the coupon spread as:

$$CS_{i,t} \;= 100 \cdot (P_{i,t} + AI_{i,t} - SIV_{i,t})$$

where $P_{i,t}$ is the bid quote (flat price) for the ith note on day t, $AI_{i,t}$ is the associated accrued interest, and $SIV_{i,t}$ is the STRIPS-Implied-Value computed from bid quotes on the replicating portfolio of fungible coupon strips.[4] An institution that replicates a note using coupon strips cannot present the strips to the Treasury in exchange for a reconstituted note. The Treasury provides this reconstitution service which requires an appropriate amount of the specific (non-fungible) principal strip. Principal strips on 10-year notes with more than a seven-year term rarely trade. Furthermore, it appears that (matrix) dealer quotes on these strips on Bloomberg are derived from the note price, so that replication arbitrage is not possible.

Our panel of coupon strips is formed by vintage, so that the first coupon strip on any date refers to the on-the-run 10-year note. Because the Treasury did not follow an established pattern of reopening notes prior to August 2003, the number of notes in our panel varies through time. On the first day of our sample, May, 16, 1997, for example, there are 36 unique 10-year notes outstanding. The Treasury generally auctions 10-year notes that expire on the 15th day of February, May, August, and November. The only exceptions to this are two notes that were initially auctioned and reopened in 1996–July 2006 and October 2006 notes. Since these two notes are off-cycle we cannot compute coupon spreads for them As such, our panel contains structurally missing data, which is described in more detail in Appendix A. Between August 2003 and November 2008, the Treasury auctioned new notes on the quarterly cycle, and followed each with a reopening auction note after one month. The current protocol started in November, 2008. Now the Treasury auctions a new 10-year note on the February, May, August, November quarterly cycle, and reopens the on-the-run note in each of the two months following its inception.

B. Auctions and Dealer Behavior

Table I provides a summary of all 10-year note auctions during each of the three periods

[4] We replicated all of the analysis in this paper using the last transaction price for the note, coupled with bid-ask quote mid-points for the strips; and the bid-ask quote mid-points for both the note and the strips. Neither of these two alternative protocols affected the qualitative results in the paper. We also replicated our analysis using yield deviations instead of pricing deviations, and the results are qualitatively unaffected. We prefer price deviations to yield deviations because the latter are subject to maturity distortions. For example, on August 13, 1997, the coupon spread on the August 15 1997 note is -2.4¢. This translates into a yield differential of 887 basis points.

that comprise our sample. The US Treasury's average monthly borrowings using 10-year notes in the three periods are: \$4.6 billion, \$8.5 billion, and \$22.02 billion, respectively. We choose to break the sample at the end of 2002 because this marks the completion of the migration of on-the-run note trading to electronic communications networks, as well as the introduction of electronic trading in 10-year note futures contracts. Figure 3 shows that our Period 2 corresponds to the time that dealers were tripling their overnight repo positions (in US Treasury securities), along with a five-fold increase in their short positions in Treasury securities with 6 - 11 years to maturity.

Table I shows that dealers purchase 78% of notes sold at auction over the period May 1997 through December 2002. Over the period January 2003 through June 2008, dealers purchase 61% of newly auctioned notes at auction and 84% at reopening auctions. In Period 3, which includes the crisis, dealers purchase 54% of notes at their original auction, 61% of notes at their first reopening auction, and 59% of notes at their second reopening auction. Foreign buyers play an increasingly important role in these auctions. Foreigners purchase an average of 6.5% of auctions over the period May 1997 through November 2002, and 13.4% from February 2003 through June 2008. During the crisis period foreigners purchase 20.9% of the Treasury's offerings of 10-year notes at auction (excluding the four special reopenings on October 8 and 9, 2008).

We obtain general collateral rates on overnight repos from Bloomberg's "last" rate, and the weighted average overnight lending rates for all 10-year Treasury notes from the Federal Reserve's securities lending program, for every day in our sample.[5] Appendix B provides details on the Fed's securities lending program.

C. Repo and Specials

Table II provides a summary of the specialness data for each of the three periods in our study. We isolate those notes that are deliverable on a standard ten-year note futures contract, that is all notes whose terms are at least 6.5 years at the expiration of the next expiring futures contract. This table also includes a summary of the program's minimum lending rates. Table II shows that virtually all notes trade on special in the repo market at various times. For example, the percentages of possible times that notes older than 3.5 years trade on special are: 1.7, 5.2, and 17.4%, in Periods 1, 2, and 3, respectively.

[5] We obtained special repo rates from Wells Fargo from the over-the-counter market for the on-the-run 10-year note for the period January 2, 2004 through August 28, 2007. Comparing these to the data from the Fed shows that the two are very close, although the Fed data will censor specialness when it is less than the Fed's minimum lending rate. Fleming and Garbade (2007) also document the similarities between securities lending by the Fed and the over-the-counter market.

In addition to the crisis, in late 2008, the Treasury's buy-back program is evident in Figure 1. Merrick (2005) notes that this program, announced in January 2000, and executed in 45 reverse auctions from March 2000 through April 2002, retired $67.5 billion of 30-year bonds and had a material effect on the STRIPS market.[6] According to the Bond Market Association (2001), a direct effect of these buy-backs was reduced market liquidity in short-term fungible coupon strips. This report suggests that reconstitution activity (of the bought-back bonds) was not offset by new stripping, so that the buy-back program severely reduced the supply of coupon strips. Figure 1 also shows that this phenomenon is the result of a clientele effect.

In particular, the lowest period for coupon spreads is April 2001. For example, on April 20, 2001, the coupon spreads of the three notes in Figure 1 are: 82¢ for the on-the-run, -24¢ for the first off-the-run, and -20¢ for Note 20. On this date the dollar amount of outstanding Treasury bonds is only 2.6% less than on April 30, 2000, when the maximum amount of bonds were outstanding prior to November 2007. However, the amount of bonds held in stripped form declined by 10.7% since that point. As Figure 1 shows, the percentage of bonds held in stripped form declined materially over the period. This shows that the institutions that tendered bonds to the Treasury are predominantly those inclined to strip the securities. By contrast institutions that hold the bonds to maturity are disproportionately those who do not strip their holdings. The fact that the supply manifests in relative prices is consistent with the findings in Krishnamurthy and Vissing-Jorgensen (2012). However in this case, the drop in the supply of strips lamented by the Bond Market Association (2001) is largely endogenous: providing another example of the complex relationship between financial institutions and asset prices.

Indeed Figure 1 also shows that the dollar amount of Treasury bonds held in stripped form is remarkably constant over the 16-year sample period. The significant decline in the percentage of bonds held in stripped form after the financial crisis reflects the increase in Treasury debt, as the dollar amount of strips increases during this period. However, there is a drop in the dollar amount of Treasury bonds held in stripped form from August 2008 to May 2009 of 8.6%, as the percentage of bonds held in stripped form declined from 28.4 to 23.8%. This decline is of the same order of magnitude as during the buy-back period, when coupon spreads fell because of the relative shortage of strips.

Figure 4 shows properties of the panel of coupon spreads in each of the three periods. Each of the youngest 31 notes is represented with a box and whiskers plot, where the whiskers show

[6]Han, Longstaff, and Merrill (2007) find that the buy-backs had no effect on the cash prices of Treasury bonds involved.

the 2.5%ile and 97.5%ile sample values, the box represents the sample interquartile range, and the line in the middle of the box is the sample median. Perhaps the most surprising feature in Figure 4 is the height of the whiskers for the coupon spreads on Notes 12, 13, and 14 in the third panel (Period 3). The coupon spreads on these notes approach 700¢ on December 12, 2008. The figure shows that the coupon spreads on Notes 12 and 13 exceed 560¢ on 18 of the 689 days in Period 3. Even notes 20 through 26 have 97.5%ile values greater than 100¢ during Period 3, whereas during Periods 1 and 2 these spreads are distributed tightly around zero.

The flattening-out of the on-the-run premium and specialness in Figure 2 is also evident in Figure 4 and Table II. Figure 4 shows that the median on-the-run premium in each of the three periods is 67¢, 27¢, and 13¢, respectively. Table II shows that as we move from Period 1 to Period 2, the on-the-run note's average specialness drops from 93 to 68 basis points while the second- and third- off-the-run notes have an increase in specialness. The table also shows that while borrowing securities from the Fed has become increasingly important in Period 3, specialness has fallen dramatically. This is the result of the fact that the Fed lowered its target for the federal funds rate target (which is a good indicator of the general collateral rate in the repo market) from 2% to 1.5% on October 8, 2008; from 1.5% to 1% on October 29, 2008, and from 1% to a range of 0 - 25 basis points on December 16, 2008. The target has remained at this level through the end of our sample period.[7]

II. Dimensionality Reduction of Coupon Spreads

In this section we explore the common components of the youngest 31 coupon spreads in our data panel.[8] Principal components analysis is our main tool in this endeavor. While principal components analysis is often (rightly) criticized as lacking statistical content and overstating the importance of common factors in a data panel, we take several measures to address these concerns. First, we use the correlation matrix instead of the variance-covariance matrix to extract the eigenvalues and eigenvectors. This is important because of the heteroskedasticity in the panel. A glance at Figure 4 clearly reveals that in all three periods the coupon spreads on younger notes are much more volatile than those on older notes.[9] Second, we use the Gibbs

[7]As we discuss below, prior to May 1, 2009, the general collateral rate served to cap specialness, since delivery failure resulted in a zero yield on cash collateral in a repo transaction.

[8]In the descriptive analysis in this paper, we use all 10-year notes for which we have all of the required data to construct coupon spreads, and all 10-year notes' repo specials. Given the historical reopening protocol, the number of notes outstanding varies over time. The maximum number is 37 following the November 2010 auction. Of a possible 1,467 days in Period 1, we have 902 observations for Note 31 and 772 observations for Note 32. Of a possible 1,432 days in Period 2, we have 927 observations for Note 31 and 644 observations for Note 32. Of a possible 689 days in Period 3, we have 670 observations for Note 31 and 668 observations for Note 32.

[9]In particular, when we use the variance-covariance matrix instead of the correlation matrix, we explain a larger

sampler to integrate over the sampling variation in the estimated correlation matrix. This allows us to characterize the statistical variation in functions of the eigenvectors and eigenvalues, and ensures robustness in identifying the components. Third, we benchmark the principal component scores to market data–Hu, Pan, and Wang's (2012) *Noise* measure and the on-the-run premium. The Gibbs sampler is useful here to integrate over the missing data in constructing the scores and also in constructing exact posterior densities of the relationships between the scores and the market data. We describe the Gibbs sampler used in our principal components analysis in Appendix C. Finally, we use factor analysis to benchmark the principal components analysis. We use the Gibbs sampler and the identification scheme of Geweke and Zhou (1996) to estimate this model, as described in Appendix D. Since factor analysis allows for uncorrelated residuals in the coupon spreads, if there are discrepancies between factor analysis and principal components analysis, these might place the results from the latter in doubt. Comparing the two also clarifies how principal components analysis identifies the common factors.

Table III contains properties of the exact posterior density of the percentage of the total correlation explained by each of the first three eigenvalues from principal components analysis and the percentage of total variance explained by the first three factors from factor analysis.[10] In Period 1 the first three eigenvalues account for 68% of the total correlation in our panel of coupon spreads. This is statistically indistinguishable from the same statistic in Period 2. This becomes 92% in Period 3, which is significantly larger than in the earlier periods. We see the same pattern in the percentages of total variance explained by the first three factors from factor analysis, which are centered at 72, 79, and 96% in the three periods, respectively. Thus the 31 coupon spreads in our panel have common factors that drive their dynamics over time, and the importance of these factors is much higher during the financial crisis.

The fact that the three factors from factor analysis explain a larger percentage of covariation than the correlation explained by the first three eigenvalues from principal components analysis is important for two reasons. First, this confirms the efficacy of principal components analysis. Since this method does not allow for the possibility of independent residuals, there is a natural concern that principal components analysis will overstate the commonality in the data. This result alleviates this concern. Second, it highlights the advantages of using the correlation matrix in principal components analysis.

proportion of total variation with principal components analysis (than when we use the correlation matrix), and the first component loads heavily on young notes, and appears to be a "slope factor."

[10]Duffee (1996) similarly evaluates the eigenvalues of Treasury notes in the 1980s, and documents that they had been becoming less homogeneous. Based on this he inferred that the market was becoming more fragmented over time.

Table III also contains the percentage explained by each of the first three eigenvalues individually, and Figures 5 and 6 display properties of the exact posteriors of the first two eigenvectors. Econometric identification of the principal components relies the uniqueness of the relative sizes of the eigenvalues. In Period 1 the first eigenvalue accounts for between 41.3 and 44.9% of the total correlations. The second eigenvalue accounts for between 13.0 and 19.4% of total correlations, and the third for between 6.2 and 11.4%. This means that each is uniquely identified under our scheme. Similar results hold for Period 2. In this period however the first component is statistically more important–explaining between 50.9 and 54.3% of total correlation, and the second and third diminish in relative importance, but there is enough deviation between them and between the third and fourth so that they remain uniquely identified.

By contrast, the third eigenvalue is not uniquely identified in Period 3. In this period the first component accounts for between 79.8 and 82.3% of total correlation, and the second accounts for between 5.5 and 9.9%. The third however only accounts for 2.2 to 3.9%, which is not significantly larger than the fourth–hence the lack of identification. The lack of identification is clear when we look at the posterior of the eigenvectors. In Figures 5 and 6, the posterior densities are tightly concentrated on the means, and the relative signs of most of the elements are the same across all of the Gibbs draws. When a component is not identified–as is the case with the third component in Period 3–the posteriors are very wide, and the relative signs change across Gibbs draws.

Table IV shows the results of factor analysis in more detail. It contains properties of the posterior density of the percentage of the total variance of each of the 31 notes' coupon spreads explained by the three factors in each period. Unlike the factor loadings and scores, this statistic from factor analysis is invariant to the identification scheme (Appendix D). This table shows the flattening-out of the on-the-run premium from a different perspective. In the first period, the three factors (which explain 72% of total variance) account for 95% of the variance in the coupon spreads of the first off-the-run note, but only 76% of the on-the-run note's coupon spread variation. As we move through time, the difference in the percentage explained of these two notes shrinks. In fact in Period 3 the first three factors account for over 95% of the total variation of the 31 youngest notes. Two factors contribute to the flattening out of the on-the-run premium and specialness in Period 2. First, the standardization of reopening auctions removed one of the reasons for heightened specialness and delivery fails in the repo market. Evidence for this is from Table I: Dealer participation in the opening auctions in Period 2 is significantly lower than in Period 1. However, dealers buy over 84% of the notes offered by the Treasury at its one-month reopenings during Period 2. Second, we see the growing size of dealer (short) inventories over

Period 2 in Figure 3–reaching almost $60 billion by late 2007. Recalling that average 10-year note issuance in Period 2 is $8.5 billion, and that average note size is less than $26 billion, highlights the importance of these positions relative to the market.

Table IV also shows that in the first two periods the variation of the coupon spreads on some of the oldest notes is largely idiosyncratic. For example in Period 1, the three factors account for only 14% of the variance of Note 31's coupon spreads. In Period 2, the three factors explain less than one-third of the total variances of Notes 28, 29, and 31's coupon spreads.

Figure 5 contains box and whiskers plots of each of the elements of the first eigenvector, in each of the three periods. The whiskers show the 95% posterior bands, the box shows the interquartile range, and the line inside the box is the median. This figure shows that the first component is a "level factor" that moves all coupon spreads in the same direction. The only negative values are on the coupon spreads of Note 28 in Period 2 and Notes 30 and 31 in Period 3. The figure shows that not only is the first component's importance increasing over time, but its effect is becoming more homogeneous as well.

Figure 6 is analogous to Figure 5 for the second eigenvector. Here the first period is unique as this component is a "slope factor," that moves the coupon spreads on the youngest six notes in the opposite direction from the spreads on the oldest 10 notes. In Periods 2 and 3 the second factor's effect is not monotonic in notes' vintages. In both of these periods it moves the oldest five notes in the panel in the opposite direction from their three immediate successors. For the coupon spreads on younger notes the effects change from Period 2 to 3. In Period 2 this factor moves the coupon spreads on the five youngest notes in the same direction as the oldest notes. In Period 3 this factor (which accounts for an average 7.8% of the total correlation) moves the coupon spreads on Notes 1 - 8 in the opposite direction from the oldest notes.

Tables V and VI explore the relationships between the three major eigenvalues and Hu, Pan, and Wang's (2012) *Noise* measure and the on-the-run premium, respectively. Hu, Pan, and Wang fit a fourth-order polynomial on each day to all Treasury bills, notes, and bonds with maturities of one month through ten years. Their *Noise* measure is the root-mean-square error of yields from this spline. They argue that this measure is large when the amount of risk capital in the market is low. By contrast, when risk capital flows into the Treasury market they argue that *Noise* shrinks.[11] They show that *Noise* is correlated with liquidity crises, and is a priced factor in hedge fund and currency carry trade returns. To analyze this we construct the score

[11] We obtained the daily *Noise* measure from Jun Pan's website: http://www.mit.edu/ junpan .

corresponding to each eigenvalue in each draw of the Gibbs sampler. Panels A through C in Table V show that the first component is significantly positively related to *Noise* in each period.[12] So when this score is a large positive number, coupon spreads on virtually all notes tend to become larger. The positive correlation between *Noise* and the first factor strengthens over time. The posterior median correlation between this factor and *Noise* increases from 30.8 to 83.4 to 94.0 through the three periods.

Whereas the percentage explained by the three factors is invariant with respect to the ordering of the data (in the identification scheme of Geweke and Zhou 1996), the factor realizations may depend on the ordering of the data. Appendix D shows the two alternative orderings which we use to identify the first factor–the natural (N) and shuffled (S) orderings. Table V also reports properties of the exact posterior density of the correlations between the first factor from factor analysis using both orderings and *Noise* in each period. As with the earlier results, factor analysis and correlation matrix-principal components analysis provide consistent results. The relationship between the first factor and *Noise* is statistically significantly positive in all three periods and significantly increasing over time (regardless of sorting).

Table V also shows that in the first and third periods the second factor is significantly negatively correlated with *Noise*. Indeed in Period 1 this correlation is significantly larger in absolute value than the correlation on the first factor. In Period 2 the second eigenvalue is uncorrelated with *Noise* and the third eigenvalue is significantly negatively correlated with *Noise*. We infer that the cross-sections of coupon spreads and *Noise* are converging over time. However in all three periods there are multiple effects on the panel of coupon spreads that cannot be captured by *Noise*. Furthermore in Period 1 an increased dispersion of coupon spreads is associated with a drop in *Noise*.

Table VI is analogous to Table V except the benchmark variable is the on-the-run premium. Hu, Pan, and Wang (2012) find that their measure has a 9.3% correlation with the 10-year on-the-run premium. In Periods 1 and 3 the dominant "level factor" is significantly negatively correlated with the on-the-run premium. This is also the case with the first factor from factor analysis. In Period 2 this relationship is reversed–when the level factor is higher (and all coupon spreads are higher) the on-the-run premium tends to be lower. In this period the correlation between the on-the-run premium and the first factor from factor analysis switches signs based on the ordering, which implies that it is not statistically significant. In any case the table shows

[12]The sign of the component scores is of course arbitrary. We have standardized the first component to have a direct effect on the youngest notes, as in Figure 5.

that the relationship between the on-the-run premium and the first three eigenvalues is small. The R^2 from regressing the on-the-run premium on the first three principal component scores is centered at 4.7%, 8.9%, and 19.2% in the three periods, respectively.

The final (and highly speculative) set of regressions examines the relationships between the principal component scores and net dealer inventory (as shown in Figure 3). We use net inventory of 6-11 year nominal Treasury coupon securities, which is available on a weekly basis, starting on July 4, 2001. Panel A of Table VII shows that in Period 2 there is some evidence of a positive correlation between net dealer inventory and each of the first three scores. The R^2 from projecting the dealer inventory on the first three scores is 56%. This is consistent with the (naive and partial equilibrium) notion that in ordinary times when dealers increase their short positions there is a general decline in coupon spreads. Of course in equilibrium we might expect that when coupon spreads are high dealers will increase their short positions. This latter behavior is more consistent with the negative relationship between first factor from factor analysis (using either ordering) in Period 2, as well between the first principal component score and dealer positions in the crisis period (Table VII, Panel B). In both periods the sign of the correlation between dealer positions and the first component is different for principal components analysis and factor analysis. This is not surprising since the equilibrium relationship between the variables is complex. Furthermore, during the crisis coupon spreads are affected by non-fundamental demand shocks that in the short-term are unrelated to the flow of risk capital. The negative spike in coupon spreads resulted from the Fed's announcement in March 2009, whereas inventories generally remained high through 2010. These inventories are also very volatile. Net inventories totaled $17.9 billion on December 8, 2010 and -20.3 billion on March 23, 2011.

III. Disentangling Coupon Spreads and Repo Specialness

As noted in the introduction repo specials are often anecdotal. In these cases, where the source and persistence of a note's specialness is unclear, we expect specialness to be disjoint from the note's coupon spread (i.e., anecdotal specialness is not priced). In our Periods 1 and 2 there are 1,135 cases where a note is (specially) borrowed from the Fed, and where the coupon spread is less than 10¢. The average coupon spread in these cases is -5.8¢, the average lending rate is 96 basis points, and the average spread over the Fed's minimum lending rate is 1 basis point; 79% of these cases occur in Period 2.

Amongst the notes that trade on special with coupon spreads less than 10¢, the maximum spread over the minimum lending rate is 255 basis points–for the 4%, November 15, 2012 note on

June 21, 2007 (at which point the minimum lending rate was 1%, so the specialness was 3.55%). This note's coupon spread was 2.3¢ on this date. This note has coupon spreads of less than 10¢ and trades on special for 41 days between August 2, 2006 and March 17, 2008. There were no outstanding loans of this security on June 19, 2007, and it had not been borrowed from the Fed since May 21, 2007. On June 19, 2007, the Fed received and accepted (all) bids for $112 million of this note, at a weighted average rate of 1.22%. On June 20, $29 million was outstanding, and the Fed received and accepted (all) bids for $69 million at a weighted average rate of 1.609%. On June 21, there were $60 million outstanding, and the Fed received bids for $193 million, and accepted $153 million (which was the entire amount available to borrow) at the weighted average rate of 3.55%.[13] This note was not borrowed from the Fed again until July 16, 2007. This note was on-the-run from November 15, 2002 through February 18, 2003. It was on special for the entire month of January, and much of February, 2003, for an average lending rate of 1.11% (11 basis points above the minimum lending rate). Over most of this on-the-run period the Fed's loans totaled $72 million of notes.

When a non-deliverable note with a negative (or low) coupon spread is borrowed specially from the Fed, this borrowing persists for several consecutive days, as in the preceding example. As another example of this phenomenon from the beginning of the sample period, 52 of the first 60 cases of specialness reported for 10-year notes with coupon spreads less than 10¢, between May, 1999 and May, 2000, are for the $8\frac{7}{8}$%, May 15, 2000 note. This note was borrowed from the Fed at an average rate of 1.55% every day in the two-week period April 3, 2000 through April 14, 2000–just one month prior to its maturity. The note's average coupon spread over this period was -2.1¢. Similarly, the $7\frac{1}{2}$%, February 15, 2005 note traded special on 32 days between November 12, 2004 and January 18, 2005–again a month prior to maturity. Over this period, the average lending rate was 1.01%–a basis point above the minimum. The maximum par accepted over this period was $854 million on November 18.

Another example of the distinction between specialness and price premia is provided by the $5\frac{3}{4}$% note of August 15, 2010, which shows up in our low-coupon-spread-cum-specialness set on 64 days, starting on June 20, 2003.[14] Figure 7 shows the coupon spread, reconstitution spread (where the note's principal payment is benchmarked to its unique corpus strip), and repo special rates for this note from May 17, 2004 through May 11, 2007. For the 64 cases when the note is on special and has a coupon spread less than 10¢, its average coupon spread is -34.7¢, and its

[13]The Fed's data on holdings, available to borrow, outstanding loans, and par submitted does not start until November, 2005.

[14]This note also is on special on January 29, 2003, (two and one-half years following its origination), when its coupon spread is 40.3¢.

average lending rate is 95 basis points, or 0.9 basis points above the minimum lending rate. This note originated in August 2000 and was reopened in November, 2000, so that the total issue size exceeds $22 billion.

It is clear from Figure 7, that once stripping and reconstitution activity start–here when the note is 4.25 years old–the reconstitution spread tends to vibrate tightly around zero. Prior to November 2004, this reconstitution spread was negative because the matrix quotes on the corpus strip were relatively high. This had no economic consequence as there were virtually no stripping and reconstitution prior to November, 2004. As of October 31, 2004, 0.07% of this note was held in stripped form. By contrast, in November, 0.34% of the outstanding note was stripped, and 0.23% reconstituted and by May 31, 2005, 6.4% of this note was held in stripped form. By August 31, 2005, 7.6% of this note was held in stripped form, which is more than twice the average ratio for five-year old notes, of 3.5%. Figure 7 shows that this note trades on special almost continuously from December 2004 through August 2005.[15]

The large negative coupon spreads from February 2005 through May 2006 are the result of the August 2010 *coupon strip* trading rich. The difference between the price of the coupon strip and the principal strip is 6.6¢ on January 31, 2005–a yield difference of -1.5 basis points. The average yield difference between the principal and coupon strip between January 3, and February 14, 2005 was 2.0 basis points. This average during June and July, 2005 was 15.6 basis points. On July 29, 2005, the yield on the August 15, 2010 principal strip was 4.192% and the yield on the same-dated coupon strip was 4.037%. The average supply of this coupon strip over the three-year period, May 2004 through May 2007 is $2.61 billion. The maximum supply was $2.72 billion on May 31, 2004. Supply declined gradually to $2.64 billion on January 31, 2005, and held at this level through June 2005. The average supply of $2.59 billion during the 15 month period while the coupon strip traded rich is statistically indistinguishable from the supply of $2.60 billion in the subsequent 12 months. Neither a drop in supply nor an increase in liquidity can explain why this fungible coupon strip trades rich over the 15-month period between the February 2005 and May 2006 auctions.

In stark contrast, prior to the financial crisis, it was rare for a note to have a high coupon spread if it were not trading on special. In our Periods 1 and 2, there are 107 cases when a non-deliverable note's coupon spread exceeds 100¢. 78 of these cases occur between March 7,

[15] Traders recall that during this period Norges Bank (the central bank of Norway) had large dollar reserves, and its trading desk, although prohibited from taking on duration exposure, was very actively trading butterfly spreads. Norges Bank bought large amounts of the August 2010 note, as the middle (long) position of a butterfly spread. The short positions were the August 2012 and August 2008 notes.

and June 27, 2008–all of these are for notes expiring in 2014: the February, 4% note; the May, $4\frac{3}{4}$% note; the August, $4\frac{1}{4}$% note; and the November, $4\frac{1}{4}$% note. The largest of these coupon spreads and the most special during this period is the May note. This note traded on special every day between March 18, and April 18, 2008, with average specialness over this period of 78.5 basis points (when the minimum lending rate was 50 basis points). Over this period, this note's average coupon spread was 127.6¢. Of these four, the February note experienced the least specialness and lowest coupon spreads over this time frame. From January 18, 2008 through May 29, 2008, this note trades on special on 9 days, and has a coupon spread greater than 100 basis points on 13 days. During this period, the two phenomena coincided on March 27, when this note's coupon spread was 104¢ and its average special rate was 50 basis points (the minimum), and on April 1, when its coupon spread was 105¢ and the special rate was also 50 basis points.

Traders attribute this episode to a coupon play. In 2008, rates had fallen–the coupon on the 5-year note issued in late February was $2\frac{3}{4}$%, and that on the 5-year note issued in late March was $2\frac{1}{2}$%. Traders suggest that foreign investors are willing to pay a premium for a higher coupon–and lower duration–than is available with similar securities. The pattern documented here is consistent in that the largest effects are seen with the highest coupon note, and the smallest with the lowest of the four coupons. The traders' explanation seems plausible. The first occurrence of a non-deliverable note's coupon spread exceeding 100¢ in our sample is in October, 1998, when the $6\frac{1}{2}$% May 2005 note appears six times, with an average coupon spread of 110.6¢. This also was a period with a steep drop in rates: the five-year note auctioned in August, 1998 had a coupon of $5\frac{1}{4}$%, and the five-year note auctioned in November, 1998 had a coupon of $4\frac{1}{4}$%.

So, prior to the crisis, we observe several instances when an older, non-deliverable note trades on special for extended periods, but the coupon spread remains close to zero, even negative. Generally the higher coupon spreads on the newer notes is tied to specialness. But there was no time when we observed high coupon spreads coupled with low specialness. Yet this is what transpired during the crisis.

IV. Public Policy

A. Delivery Fails in Repo

Figure 8 shows delivery fails to receive Treasury securities in the repo market over the period July 4, 1990 through the end of our sample period (March 31, 2011). The first spike in fails occurs after the terrorist attack on the World Trade Center in September, 2001. The second spike occurs in the fall of 2003. The reason for this spike is unusually high shorting activity in the May 15, 2013 $3\frac{5}{8}\%$ 10-year note in the second half of 2003. Fleming and Garbade (2004, 2005) discuss this situation. Traders say that this note was heavily shorted, and there were widespread rumors (unfounded) that the Treasury would reopen this note. In the event, the Treasury never reopened the note, so chains of delivery fails that lasted for several months ensued. After this episode the Treasury has followed a much more predictable pattern of opening auctions and re-openings.

Because the negative on-the-run premium occurs only twice in the period–the second time following the bankruptcy of Lehman Brothers–we explore these incidents in more detail. The Treasury issued $18.25 billion of the May 2013 note on May 15, 2003. While it traded on-the-run this note's behavior was not unusual. Its average coupon spread during this period was 172¢. After one month it shows up as being borrowed from the Fed (i.e., on special) for 44 of the next 45 days, with an average lending fee (specialness) during this period of 106 basis points. This figure shows that after it goes off the run, both the coupon spread and specialness *increase*. During the 60 trading days that the August 2013 note is on-the-run, the May 2013 note's average coupon spread is 215¢, and the note is borrowed from the Fed on 57 days, at an average rate of 123 basis points. Recall that the minimum lending rate was lowered on June 25, 2003 from 150 to 75 basis points. By comparison, the average coupon spread of the on-the-run note over these 60 trading days was 159¢. Since we have the unique situation that the off-the-run note trades on special 56 basis points higher than the on-the-run note, there is a negative on-the-run premium, (below -100¢) during this period. During the 60 trading days after the November 2003 auction, the May note continues to trade on special for 44 days, and it has an average coupon spread of 156¢, while the on-the-run note's coupon spread averaged 140¢. Conditions in the May 2013 note only start to stabilize after the May 2004 auction. During the quarter that the May 2014 note was on-the-run, the year old May 2013 note traded on special on 17 of the 64 trading days, and had an average coupon spread of 130¢. The on-the-run note's average coupon spread during this quarter was 137¢ and the average coupon spread of the first off-the-run was 95¢.

Figure 2 shows a similar negative on-the-run premium following the November 2008 auction. In this case, the August 2018 note was on-the-run at the time of Lehman Brothers' collapse, which contributes to the heightened fails and increased price on this note even after it goes off the run. Figure 2 shows a stark difference between this event and the 2003 event. In the 2003 case the figure shows heightened specialness in the May 2013 note after it goes off the run. However there is no specialness of the August 2018 note after it goes off the run. In the absence of a fails penalty, when general collateral rates are close to zero, strategic delivery failing is prevalent. These two cases also help to identify the reasons for the on-the-run premium. It is often claimed that this premium reflects the relatively higher liquidity of the on-the-run note. But this hypothesis is not consistent with the decline in the on-the-run premia as its liquidity advantage widens, nor can it explain these two counterexamples. Instead, as Duffie (1996) and Vayanos and Weill (2008) suggest, all of the empirical facts are consistent with the on-the-run premium reflecting relative scarcity as collateral (in repo). In the 2003 episode, the May note remained in high demand as a result of confusion concerning the Treasury's auction plans. By contrast in the context of the 2008 financial crisis, the average specialness (standard error) of the first off-the-run (August 2018) note was 2 basis points (with a standard error of 0.7 basis points) whereas average specialness for the on-the-run (November 2018) note was 4 basis points (0.5 basis points). The low general collateral repo rates contributed to historic high levels of strategic delivery fails in this setting.

The common wisdom concerning the financial crisis is that concerns about asset quality led to a run on the shadow banking system (repo and asset-backed commercial paper), see for example Hanson, Kashyap, and Stein (2011) and Gorton and Metrick (2010). Those holding liquid capital such as pension funds and money market funds became increasingly concerned about their counterparty exposure in the repo market, and the quality of asset pools backing commercial paper. Therefore, levered players such as hedge funds and investment banks lost their primary funding source and were forced to sell some of their holdings. This in turn had a downward effect on asset prices, further exacerbating counterparty risks. This story is consistent with the pattern of primary dealer holdings of 6 - 11 year US Treasury securities as well as the size of primary dealers' repo positions shown in Figure 3. From the beginning of this data in July 2001, through mid-2008 dealers maintained large short positions in this market.

The crisis manifests in US Treasury markets later than in other settings. The dealers' largest short position in 10-year notes was reached on July 18, 2007, when they were net short \$56.9 billion. Since then short positions have been steadily unwound and in February 2009, primary dealer net holdings became positive. The long position peaked in May 2010, at around \$22 billion. Figure 3 also shows that overnight repo positions in US Treasury securities peaked at almost \$3 trillion in March, 2008, and declined steadily to a low value of \$1.4 trillion in December, 2009. The drop was starker in term repo. Primary dealers' term repo in US Treasuries fell from \$1.8 trillion in June 2008 to \$0.6 trillion in January 2009. This level is the lowest since the start of this data. Overnight repo had doubled from June 2004 through March 2008, while term repo remained flat (at around \$1.4 trillion) over the same period. As Gorton and Metrick (2010) note, the growth in leveraged balance sheets prior to the crisis was financed, in large part using overnight money. (Although as noted in the introduction, the drop in intra-dealer bilateral repo can be misleading.)

So dealer balance sheets start to reflect the strains of the crisis by August 2008, when coupon spreads start to widen. However, the spike in coupon spreads occurs several months later. Delivery fails reached \$2.7 trillion in par value of all US Treasuries on October 15, 2008, a month after Lehman Brothers' bankruptcy. Repo settlement was exacerbated by the historically low general collateral rates in this period. Prior to May 1, 2009, there was no (added) cost-of-fail in this market. So the cost of failing to deliver is the general collateral rate. Evans, Geczy, Musto, and Reed (2009) show that failing to deliver is a valuable option in equity markets, when rebate rates are below zero. In the equity markets this option was limited to dealers prior to 2005, and is no longer possible (after Reg SHO in 2005).

As noted in the introduction the Treasury Market Practices Group (TMPG) and the Securities Industry and Financial Markets Association (SIFMA), with the cooperation of the US Treasury and Federal Reserve, promulgated a minimum delivery fails charge of 300 basis points for US Treasury securities on May 1, 2009. This penalty is irrelevant when the general collateral rate exceeds 3%, as the standard result of failing to deliver against a repo is forfeiture of interest on the cash collateral.[16] However during the financial crisis, general collateral repo rates are less than 10 basis points, and often 1 basis point or lower. So with this charge the cash collateral in a repo transaction earns a negative rate. The Federal Reserve also now charges this fail penalty for all delivery fails on overnight loans from its System Open Market Account (SOMA).

The inset of Figure 8 magnifies the dealer receive fails for the eight months around the introduction of the new fee. The average (standard error of) daily fails-to-receive in the four months before the addition of the fails charge was \$107.0 billion (\$13.6 billion). This fell to \$56.6 billion (\$14.8 billion) in the four months following May 1, 2009. While the drop is statistically significant, it is clear that there are still large variations in receive fails. Cumulative fails in the week of July 8, 2009 are \$238.0 billion. The aggregate penalty for this level of fails in this week exceeds \$99 million. The level of fails continues to fall through the end of our sample. Average (standard error of) receive fails from May 1, 2009 through March 30, 2011 are \$28.7 billion (\$3.3 billion).

[16]The exact formula to compute the fails charge is $C = \frac{1}{360} \cdot .01 \cdot \max(3 - R, 0) \cdot P$, where R is the Federal Reserve's stated federal funds rate target, and P is the dollar value of the trade proceeds.

Consider repo borrowing in the 10-year note complex in the five months preceding and following this regulatory change. From December 1, 2008 through April 29, 2009, 781 10-year notes were borrowed from the Fed's overnight securities lending program at an average rate of 0.76 basis points above the minimum. During this period the maximum lending fee is 29.30 basis points, and the standard deviation of the spread between this rate and the minimum is 4.88 basis points. In the five months following the introduction of the 300 basis point fails penalty on May 1, 2009, ending on September 30, 2009, 382 10-year notes were borrowed from this program. During this period the average rate above the minimum is 12.36 basis points, the maximum is 310.60 basis points, and the standard deviation is 50.01 basis points. So the effect of the fails charge is seen more clearly in special repo rates than in delivery fails. There was an economically and statistically significant increase in repo specialness following the introduction of the fails penalty. While this is consistent with optimizing behavior by dealers, the level of delivery fails remains high by historical standards over this five-month period.

B. Quantitative Easing

1. QE-I

On November 25, 2008 the Federal Reserve announced that it was initiating the first round of quantitative easing, (QE-I), with planned purchases of $100 billion of the debt of Fannie Mae and Freddie Mac, and $500 billion in mortgage-backed securities (MBSs), over a six-month span. On March 18, 2009, Federal Reserve chairman Bernanke stated that this program will extend to $200 billion in agency debt and $1.25 trillion in agency MBSs. This program was extended to US Treasury securities as well: the Federal Open Market "Committee decided to purchase up to $300 billion of longer-term Treasury securities over the next six months." The Fed announced that it was extending this program on November 3, 2010: "the Committee intends to purchase a further $600 billion of longer-term Treasury securities by the end of the second quarter of 2011, a pace of about $75 billion per month." We describe the mechanics of the quantitative easing program in Appendix B.

As mentioned in the introduction, the importance of the March 18 announcement on coupon spreads is evident in Figure 1. From March 17 to March 19, the coupon spread of the on-the-run note fell from 491 to 370¢. While the effect of this announcement on the coupon spreads of Notes 2 – 6 is of the same magnitude as on Note 1, the effect on older notes' coupon spreads was less dramatic, and not monotone. For example the March 17 (March 19) coupon spreads for Notes 9, 11, 14, 16, 24, 25, and 29 are: 395¢ (371¢); 442¢ (327¢); 323¢ (323¢); 271¢ (286¢); 65¢ (93¢);

134¢ (68¢); and 26¢ (8¢), respectively.

Mitchell and Pulvino (2012) suggest that the financial crisis affords the opportunity to measure the speed of capital–that is how long it takes for new capital to take advantage of the arbitrage opportunities created by the retreat of traditional risk capital from the markets (Duffie 2010). The fact that coupon spreads decline dramatically on this announcement and before the Fed actually started to purchase Treasury notes and bonds, suggests that both the lack of arbitrage capital *and* a non-fundamental supply shock are necessary to beget tradeable optical arbitrage. The Fed's announcement *per se* serves to reverse the initial non-fundamental supply shock, since it had no effect on the availability of arbitrage capital in the market.

Figure 9 shows the (ask quote) yields-to-maturity on the two Treasury securities that expire on February 15, 2019, the newly-issued $2\frac{3}{4}\%$ 10-year note and the $8\frac{7}{8}\%$ 20 year old 30-year bond, along with the coupon spread (measured in ¢) on the former. The two securities are not perfect substitutes–the bond's duration is 7.1 years, while the new note's is 8.6 years, as of February 17, 2009. The Treasury issued $22 billion of the new 10-year note on February 17, 2009, and by April 15, 2009, there were $58.7 billion outstanding. By contrast, the original issue size of the 30-year bond was $19.2 billion, and the Treasury retired $6.1 billion during their buy-backs of 2000-2002. Between March 31 and October 31, 2009, the Federal Reserve purchased 15% of the outstanding amount in this bond. The Fed's eight purchases over this time frame are shown in Figure 9, as is the Fed's single purchase of 1.7% of the amount outstanding in the 10-year note during this period. On March 31, 2009, 27% of the bond was held in stripped form. Clearly some of the Fed's purchases resulted in reconstitution, because on October 31, 2009, only 20% of the outstanding amount of the bond was held in stripped form.

Several studies, including D'Amico and King (2013) infer that the first round of quantitative easing depressed 10-year Treasury yields. A glance at Figure 9 shows that standard event-study methodology (such as in Gagnon, Raskin, Remache, and Sack 2011, and Krishnamurthy and Vissing-Jorgensen 2011) will tend to infer that the announcement of the extension of the first phase of quantitative easing to the Treasury market had a large negative effect on 10-year yields. However, the figure shows that within two months yields returned to previous levels, whereas the effect on coupon spreads is permanent. Fleckenstein, Longstaff, and Lustig (2013) find no relationship between the amount of purchases by the Fed and the TIPS mispricing measure–on a monthly basis. In coupon strips the effect occurs on the announcement.

This pairwise comparison between same-dated notes and bonds is the type used in Musto, Nini, and Schwarz (2011). The differences in yields are large. On March 17, 2008, for example the on-the-run 10-year note yield is 3.008% and the 20 year old bond yield is 3.389%. Musto, Nini, and Schwarz attribute the spread to a breakdown in the repo market and preference for liquidity by institutions. The Fed had $1.25 billion in the on-the-run notes available to lend from its SOMA account, but none was borrowed on March 16 or 17. Over the week, an average of 15% of the Fed's holdings that were available to lend was borrowed, at an average special rate of 1.4 basis points. In the three weeks prior to the March reopening auction, roughly 100% of the Fed's available holdings in this note were loaned out every day, at an average special rate of 19.8 basis points. So we see the typical pattern of dealers using a reopening auction to cover their short positions–reducing the specialness of the note.

2. QE-II

The Fed announced a second round of quantitative easing on November 3, 2010 (QE-II), in which the Fed would purchase $600 billion in long term securities over the next eight months. In addition it would reinvest another $250-300 billion of proceeds from earlier investments. Figure 10 shows the (bid quote) yields-to-maturity on the on-the-run $2\frac{5}{8}$% 10-year note at the time of this announcement along with its 20 year old "twin," a 30-year, $8\frac{3}{4}$% bond that also matures on August 15, 2020, over the period August 16, 2010 through March 31, 2011. From November 2 to November 4, the on-the-run note's yield fell from 2.59 to 2.493%. By November 9, this yield was back to 2.659%. So, as with QE-I, the immediate drop in yields upon the program's announcement is temporary. The contrast with the market conditions 20 months earlier (Figure 9) is stark. Between August 16, 2010 and November 2 the average spread between these two August 2020 security yields was -3.87 basis points with a standard error of 0.20 basis points. That is the 20 year old bond's yield was *lower* than the on-the-run 10-year note's yield. The mean twin spread (standard error) over the 100 days following the QE-II announcement is -14.17 (0.21) basis points. When QE-I was announced the on-the-run note was selling at a 38.1 basis point lower yield than its 20 year old twin, and 100 days later this spread had fallen to 3 basis points. Figure 10 also shows all Fed purchases of both of these securities over the time frame. When QE-II was announced there were $17.2 billion of the 20 year old bond outstanding[17] and $67.85 billion in the on-the-run 10-year note. The Fed did not purchase any of the new 10-year note during this 6.5 month period and made fourteen purchases of the 20 year old bond, totaling $5.4 billion.

[17]The Treasury auctioned $10.46 billion in August 1990 and another $10.95 billion in November 1990. The Treasury retired $4.19 billion of the note during its "buy back" period, in 15 separate auctions between March 16, 2000 and April 23, 2002.

The relationship between these two securities is so surprising that we explore two additional dimensions of their market dynamics over this period. The new on-the-run note trades on special on 44 of the 62 (trading) days that it is on-the-run. Over this term the average amount borrowed from the Fed is $654 million, at a weighted average rate of 15.6 basis points. After it goes off the run, on November 15, 2010, through March 31, 2011, it trades on special on 20 of the 95 trading days. The average amount borrowed from the Fed is $59 million. The rate on all of these borrowings from the Fed was (the minimum) 5 basis points. The 20 year old bond traded on special only once during the August 16 - November 15 period: $2 million (par value) of the note was borrowed at 5 basis points on November 3. For the November 16 through March 31 2011 period, this bond was borrowed from the Fed 19 times, at an average amount of $15.9 million, all at 5 basis points. While the 20 year old bond is borrowed almost as frequently as its new 10-year twin, after the latter goes off the run, the new note is borrowed more heavily. So it is unlikely that differences in specialness, per se, can explain the curious yield difference between these two securities.

From the inception of the second phase of quantitative easing through March 31, 2011, the Fed bought $5.4 billion of the 20 year old bond in 14 auctions. Over this period, the bid-ask spread in the secondary market on this bond is stable at $0.0625 per $100 par value. On average, the Fed pays more for the bond than its secondary market quotes. The value-weighted average of the difference between the average price paid by the Fed at auction and the mid-point of the closing bid-ask spread is $0.183 per $100 par value. The maximum difference was on the first date, November 17, 2010, when the Fed purchased $848 million par units of this bond at a value-weighted premium to the mid-point spread at close of $0.827. Despite this outlier, the difference between the prices paid by the Desk for this bond and the secondary market values are not statistically significant. Of the 14 operations, the difference is positive seven times, the equally weighted average difference between what the Fed paid and the closing quote mid-point is $0.109 with a standard error of $0.117. A dealer could tender securities to the Fed at an aggressive price. If the dealer does not own the securities it can borrow them from the Fed for 5 basis points, as it waits for customer sell orders to cover the short exposure. While the heightened borrowing activity of this bond from the Fed during this period is consistent with the occurrence of this trade, it was not significantly profitable.

V. Conclusion

In the absence of frictions coupon spreads would all be zero. Add “garden variety” transactions costs and they would vibrate randomly around zero, and the standard deviation of this noise would measure the scale of trading costs. Note 20 in Figure 1 between the end of the Treasury’s buy-back program (April 2002) and the first quarter of 2008 exhibits this behavior. If this were the whole story behind coupon spreads then they would not be driven by any systematic factors. Furthermore, we would not learn about the relationships between institutions and frictions and asset prices by studying them. However, coupon spreads are affected by institutions and frictions in both ordinary and crisis times. The high levels of coupon spreads on recently-issued notes before the financial crisis cannot be explained by simple transaction costs. Specialness in the repo markets drives a wedge between a note’s value and market price, since its owner may use the note as collateral to obtain a cash loan at below-market cost. Our analysis of coupon spreads trains a high-powered microscope on relative prices, and value differences due to different repo specialness become visible. Prior to the crisis the one instance when the on-the-run premium was negative corresponds to heightened specialness of the first-off-the-run note relative to its predecessor.

There are important systematic factors driving the panel of coupon spreads. The most important of these is a “level factor,” whose importance is increasing over time. Its importance grows prior to the crisis as the uniqueness of the on-the-run note diminishes, and recently specialness is spread across several notes, in the context of increased risk capital. The existence of additional important systematic factors serves as a reminder that there are multiple aspects and manifestations of limits to arbitrage in market prices. In sharp contrast to the preceding decade, the link between coupon spreads and expected specialness is broken during the crisis. The link between the relative supply of strips also seems broken. This disjunction from the past serves as a reminder that a drop in risk capital is not a sufficient reason for relative prices to afford arbitrage opportunities. There has to be some non-fundamental supply shock.

Appendix A. Data

Bloomberg collects quotes from several dealers and provides the inside posted bid and ask quotes. For notes, dealers post quotes using Street convention on *prices* using a minimum tick size of $\frac{1}{64}$ of one dollar. For strips, dealers post quotes using Street convention on *yields-to-maturity*, using a minimum tick size of $\frac{1}{10}$ of a basis point. Street convention assumes next business day settlement. For the notes this means that the posted quote is an invoice price net of the accrued interest as of the next business day. Bloomberg provides a Treasury settlement calendar which we use to identify holidays. Street convention also entails an "Actual/Actual" treatment of future coupons and maturities–that ignores bad days in assigning coupon and settlement dates. Jordan, Jorgensen, and Kuipers (2000) also use only bid quotes, and describe the importance of using the correct settlement procedure (to compute accrued interest).[18]

In 1996, the Treasury auctioned six new 10-year notes including new notes in July and October. Since there are no fungible coupon strips corresponding to these two notes there are three, six, nine, or 12 months of missing coupon spread data (depending on the subsequent auction reopening cycle), for all vintages of notes in our sample, except for the first two. For example starting on May 15, 1997, the first date in our sample, Note 3 has 64 missing observations and Note 4 has 188 missing observations. Note 5 is missing 186 observations between August 15, 1997 and May 18, 1998. Note 12 is missing 252 observations, between August 17, 2000, and August 17, 2001. Therefore the amount of structurally missing data in our sample is material. Additionally, since constructing a coupon spread requires valid quotes from Bloomberg on all coupon STRIPS, there are occasional randomly missing data as well. For instance, over the 3,468 days in the sample, there are 41 missing observations of the on-the-run note.

The largest proportion of missing data is in our Period 1. There are 1,404 trading days in this sample period, May 15, 1997 through December 31, 2002. For the 31 notes of most recent vintage, we have 38,500 valid coupon spreads, so that over 11.5% of the values are missing. These missing data give rise to two problems. First, the (unbalanced) sample variance-covariance matrix is not of full rank. Second, we need values for all of the notes on each date in order to construct scores from either principal components or factor analysis. The Gibbs sampler provides a way to deal with these problems.

Appendix B. The Federal Reserve

Securities Lending

The Federal Reserve plays an important role in the repo market for US Treasury securities. The Fed started lending securities from its System Open Market Account (SOMA) in 1969. It started its current daily afternoon auction format on April 26, 1999. Dealers may bid on any Treasury securities at this auction. The Fed uses a multiple-price auction and the loans are overnight in term. The bid corresponds to the specialness of the security, since this is not a repo market–the Fed does not want securities lending to affect the monetary base. The Fed imposes a minimum bid rate in an attempt to limit this program to those securities trading on special in the repo market.

Primary dealers submit bids in increments of $1 million, via FedTrade (the Fed's electronic auction system). Bids are accepted until 12:15 pm. The minimum bid rate was set originally at 150 basis points, lowered to 100 basis points on September 18, 2001, and to 75 basis points on June 25, 2003. This rate was increased to 100 basis points on July 1, 2004, and reduced to 50

[18] Jordan, Jorgensen, and Kuipers' (2000) data end in September 1996, so there is no overlap with our sample. They note that dealer ask quotes are often simply derived from the bid quotes. Dealers still post "matrix" quotes on the ask side, whereas their bid quotes are considered more meaningful economically.

basis points on August 21, 2007. This minimum fee was lowered to 10 basis points on October 27, 2008, and to 1 basis point on December 18, 2008. It was raised to 5 basis points on April 7, 2009. The available supply comprised 45% of SOMA holdings (on a security-by-security basis) in 1999. This was raised to 65% on May 15, 2002, and to 90% on August 22, 2008. FedTrade provides this supply (called the theoretical amount available) to the primary dealers.

A winning bidder must post an alternative security as collateral. The amount of collateral reflects haircuts in the repo markets. In the event of a delivery fail, prior to May 1, 2009, the Fed charged a penalty fee equal to the general collateral rate in addition to the lending fee. Subsequent to May 1, 2009, the Fed follows the minimum delivery fails convention implemented by the Treasury Market Practices Group and the Securities Industry and Financial Markets Association, which stipulates that when the general collateral rate is less than 3%, the delivery fails charge will be 300 basis points.

A Fed study published in February 2008, reports that the average daily award over the period April 1999 through December 2007 is \$2.1 billion. The program has grown in importance. The Fed loaned par value of \$25.8 billion on the day that Lehman Brothers filed for bankruptcy, September 15, 2008, and \$26.1 billion on October 23, 2008. The maximum value of securities borrowed from the Fed in this program in our sample is \$33.8 billion in par value on March 31, 2011. Borrowings are volatile. In the first quarter of 2011, the average par value of SOMA holdings on overnight loan was \$16.5 billion with a standard deviation of \$3.8 billion.

The mechanics of quantitative easing

The purchases by the Fed in its quantitative easing program are conducted as permanent open market operations. The Fed announces its desired purchase amount and eligible securities, and receives tenders from dealers via FedTrade from 10:15 through 11:00 am on the announced dates. This is a discriminating price auction, and the Fed uses a proprietary model as well as prices in the secondary market to award securities. From the seller's perspective these sales are identical to secondary market transactions, as they involve next business day settlement via Fedwire. The Fed notes that it "will refrain from purchasing securities that are trading with heightened scarcity value in the repo market for specific collateral or that are cheapest to deliver into active Treasury futures contracts." D'Amico and King (2013) analyze the Fed's choice of securities to purchase at auction during QE-I. It is clear that during this period, the Fed purchased those securities that were trading cheap relative to comparable securities.

Appendix C. Principal Components Analysis

To analyze the structure of coupon spreads with principal components analysis, we start by assuming that these spreads are 31-variate normally distributed with mean vector μ and variance-covariance matrix, Σ. We integrate over the missing data by drawing each missing coupon spread, for example, $x_{t,j}$ in turn as follows. First re-order Σ so that row j becomes the first row, and the first column is the transpose of this row. Then we partition the variance-covariance matrix as follows:

$$\Sigma = \left[\begin{array}{c|c} \Sigma_{11} & \Sigma_{12} \\ \hline \Sigma_{21} & \Sigma_{22} \end{array}\right]$$

Here, Σ_{11} is a scalar–the (unconditional) variance of the j^{th} coupon spread. Σ_{12} is a $(K-1)$ vector, $\Sigma_{21} = \Sigma_{12}^{'}$, and $\Sigma_{2,2}$ is $(K-1) \times (K-1)$. Conditional on the other 30 coupon spreads on date t, then the full conditional density for the missing value is normal with mean $\hat{\mu}_j$ and variance $\hat{\sigma}_j^2$, where:

$$\hat{\mu}_j = \mu_j + \Sigma_{12}\Sigma_{22}^{-1}(X_{t,-j} - \mu_{-j}) \tag{1}$$

$$\hat{\sigma}_j^2 = \Sigma_{11} - \Sigma_{12}\Sigma_{22}^{-1}\Sigma_{21} \tag{2}$$

Here, μ_j is the unconditional mean of the j^{th} coupon spread.

Once we have draws for all the missing values, we draw the mean vector and variance-covariance matrix of the coupon spreads:

$$\mu|\Sigma \sim N(\bar{x}\,,\, T^{-1}\bar{\Sigma}) \tag{3}$$

$$\Sigma|\mu \sim IG(\hat{\Sigma}\,,\, T) \tag{4}$$

Here $\hat{\Sigma}$ is the maximum likelihood estimator of Σ (which is conditional on μ), and $\bar{x}$ is the sample mean. IG refers to the inverse gamma distribution.

We transform Σ to the correlation matrix, and obtain the eigenvalues and eigenvectors at this draw. Following the idea behind the Gibbs sampler, we then get a new draw from the missing variables– conditioned on the data and the latest draw of μ and Σ, and then draw μ and Σ conditioned on these draws, etc. This yields the marginal (posterior) distributions of the eigenvalues, eigenvectors, principal component scores, and correlations between these scores and $Noise_t$. The Gibbs sampler converges within 1,000 draws. We discard the first 1,000,000 draws as a burn-in, and keep the next 100,000 draws. This produces a set of 100,000 realizations of all of our functions of interest–comprising the marginal posteriors on all aspects of the principal component analysis.

We use these eigenvectors and the (augmented) data to construct the principal component scores for this draw. We evaluate the correlation between this draw from the scores and Hu, Pan, and Wang's (2011) $Noise_t$, for example.

There are two potential "aliasing" problems with this algorithm. First, the components may shift identities from one Gibbs draw to the next. For example, the seventh principal component from the last Gibbs draw switches places with that draw's eighth principal component in this draw. This situation is most likely when two components' marginal explanatory powers are very similar to one another. For this reason, we only use the largest three eigenvalues in Periods 1 and 2, and the largest two eigenvalues in Period 3–where this problem does not arise in our analysis. The second problem concerns the fact that the components are not uniquely identified (to an orthonormal transformation). This can manifest by a change in the sign of an eigenvector from one draw to the next. We address this problem by identifying the largest element of each eigenvector in absolute value from the first draw, and multiply the eigenvector by 1 or -1 so that this element's sign is constant across draws.

Appendix D. Factor Analysis

For factor analysis, we use the identification scheme of Geweke and Zhou (1996). Under this model, all coupon spreads are linear functions of three orthogonal factors plus a residual that is normally distributed and independent across the coupon spreads. As Geweke and Zhou note, the joint distribution of the coupon spreads and factors under this model is:

$$\begin{pmatrix} \mathbf{f}_t \\ \mathbf{S}_t \end{pmatrix} \sim N\left[\begin{pmatrix} \mathbf{0} \\ \boldsymbol{\alpha} \end{pmatrix}, \begin{pmatrix} \mathbf{I} & \boldsymbol{\beta}' \\ \boldsymbol{\beta} & \boldsymbol{\beta}\boldsymbol{\beta}' + \boldsymbol{\Upsilon} \end{pmatrix}\right] \tag{5}$$

In our set-up, $\mathbf{f}_t$ is a 3-vector of factors at time t; $\mathbf{S}_t$ is a 31-vector of coupon spreads at time t; $\boldsymbol{\alpha}$ is a 31-vector of coupon spread means; $\boldsymbol{\beta}$ is a (31×3) matrix of factor loadings; and $\boldsymbol{\Upsilon}$ is a diagonal (31×31) residual variance matrix.

So we deal with missing data by taking a draw from the residual–conditional on the corresponding diagonal element in the residual variance-covariance matrix (which is a diagonal matrix), and then obtain a draw from the missing coupon spread by adding this residual to the sum of the factor loadings for this note, times the factor scores for this date (available at this iteration of the Gibbs sampler). In this manner, we construct marginal posterior distributions of functions of the factor analytic model by integrating over the missing data and model parameters, under the likelihood function. We place a diffuse prior over the parameter space.

We use 3 million burn-in draws and keep the following 100,000 draws from the missing data / parameter space to construct exact posterior densities of functions of interest. To examine the effect of the arbitrary identification scheme on the posterior, we use two alternative orderings of the data. We refer to the first ordering as the natural order–here coupon spreads are numbered according to their vintage. With this scheme, the identifying restrictions mean that:

$$S_{1,t} = \alpha_1 + \beta_{1,1} \cdot f_{1,t} + \epsilon_{1,t} \tag{6}$$

with $\beta_{1,1} > 0$;

$$S_{2,t} = \alpha_2 + \beta_{2,1} \cdot f_{1,t} + \beta_{2,2} \cdot f_{2,t} + \epsilon_{2,t} \tag{7}$$

with $\beta_{2,2} > 0$; and

$$S_{3,t} = \alpha_3 + \beta_{3,1} \cdot f_{1,t} + \beta_{3,2} \cdot f_{2,t} + \beta_{3,3} \cdot f_{3,t} + \epsilon_{3,t} \tag{8}$$

with $\beta_{3,3} > 0$.

We re-order the coupon spreads as follows: Notes 6 - 12 are ordered 1 - 7, Notes 1 - 5 are ordered 8 - 12, and 13 - 31 remain 13 - 31. We note that because of the non-uniqueness of the loading and factor space, the percent explained of a coupon spread's total variance is not affected by its ordering. Thus, the percentage of overall variance explained by the 3-factor model in Table III, as well as the percentage explained for each individual coupon spread in Table IV are not affected by this ordering.

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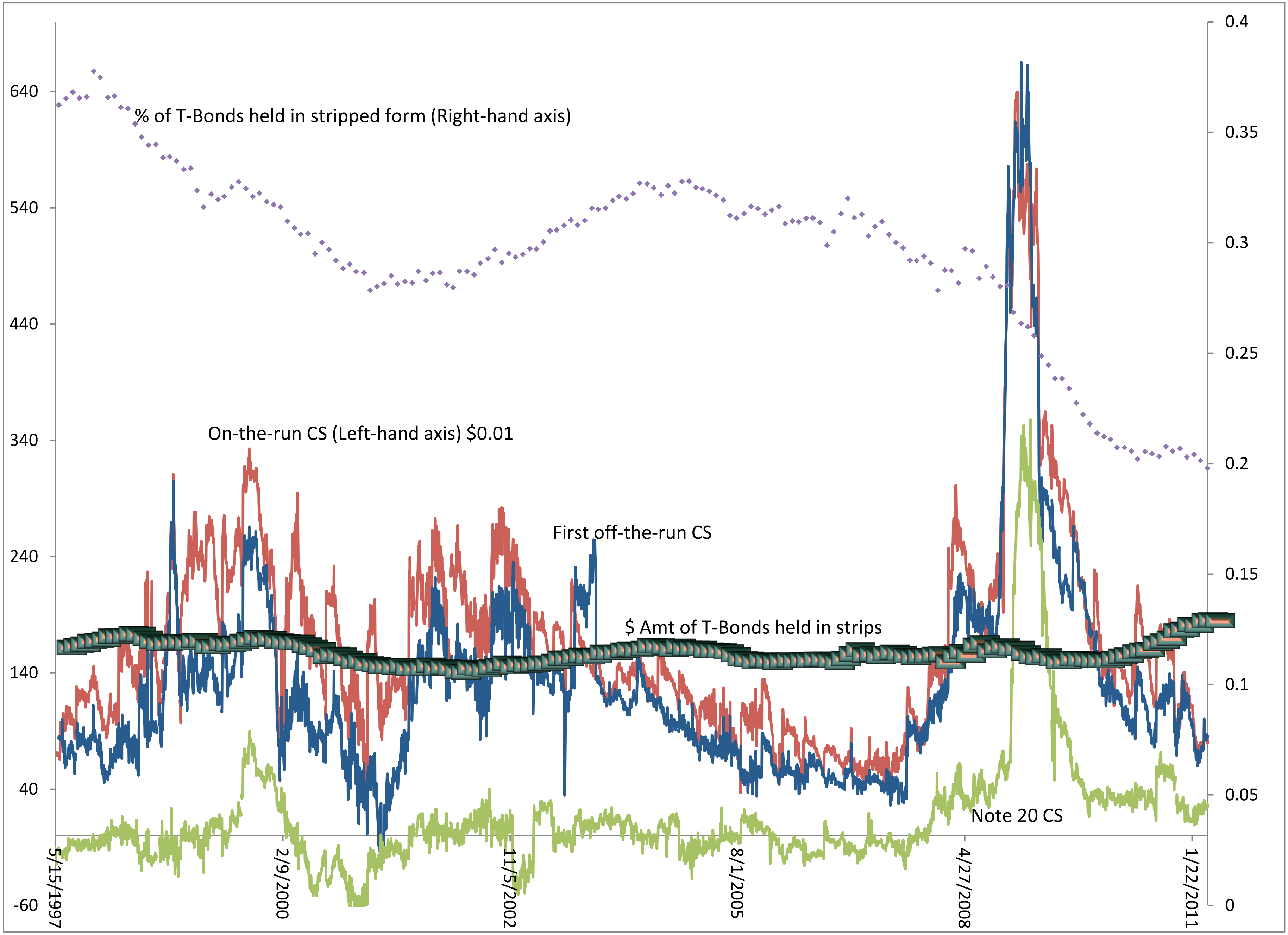

Figure 1. Time series of selected coupon spreads and STRIPS supply. This graph depicts daily coupon spreads on: the on-the-run 10-year US Treasury note, the first off-the-run 10-year US Treasury note, and Note 20 (a non-deliverable 10-year US Treasury note with 2.66 to 5.25 years to maturity), in cents per $100 par value (on the left-hand axis). It also shows the monthly dollar amount of Treasury bonds held in stripped form (in $ billions on the left-hand axis), and the percentage of Treasury bonds held in stripped form (on the right-hand axis). The sample period is May 15, 1997 through March 31, 2011.

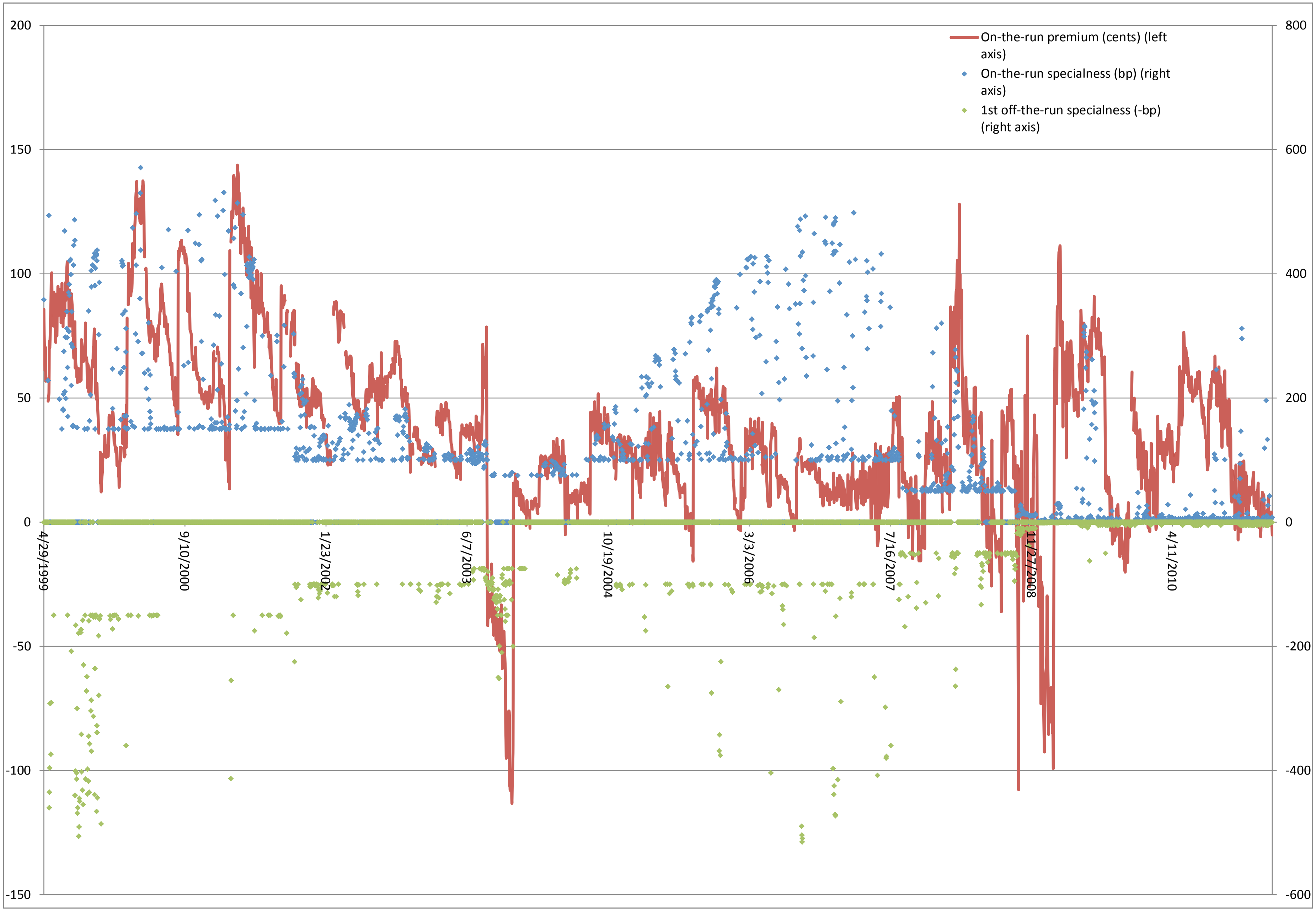

Figure 2. Time series of the on-the-run premium and specialness of the on-the-run and first off-the-run notes. The on-the-run premium is the daily difference between the on-the-run and first off-the run 10-year US Treasury note coupon spreads in cents per $100 par value. Specialness is the daily average borrowing fee from the Federal Reserve's securities lending program. The negative of the first off-the-run note's specialness is shown. The sample period is April 29, 1999 through March 31, 2011.

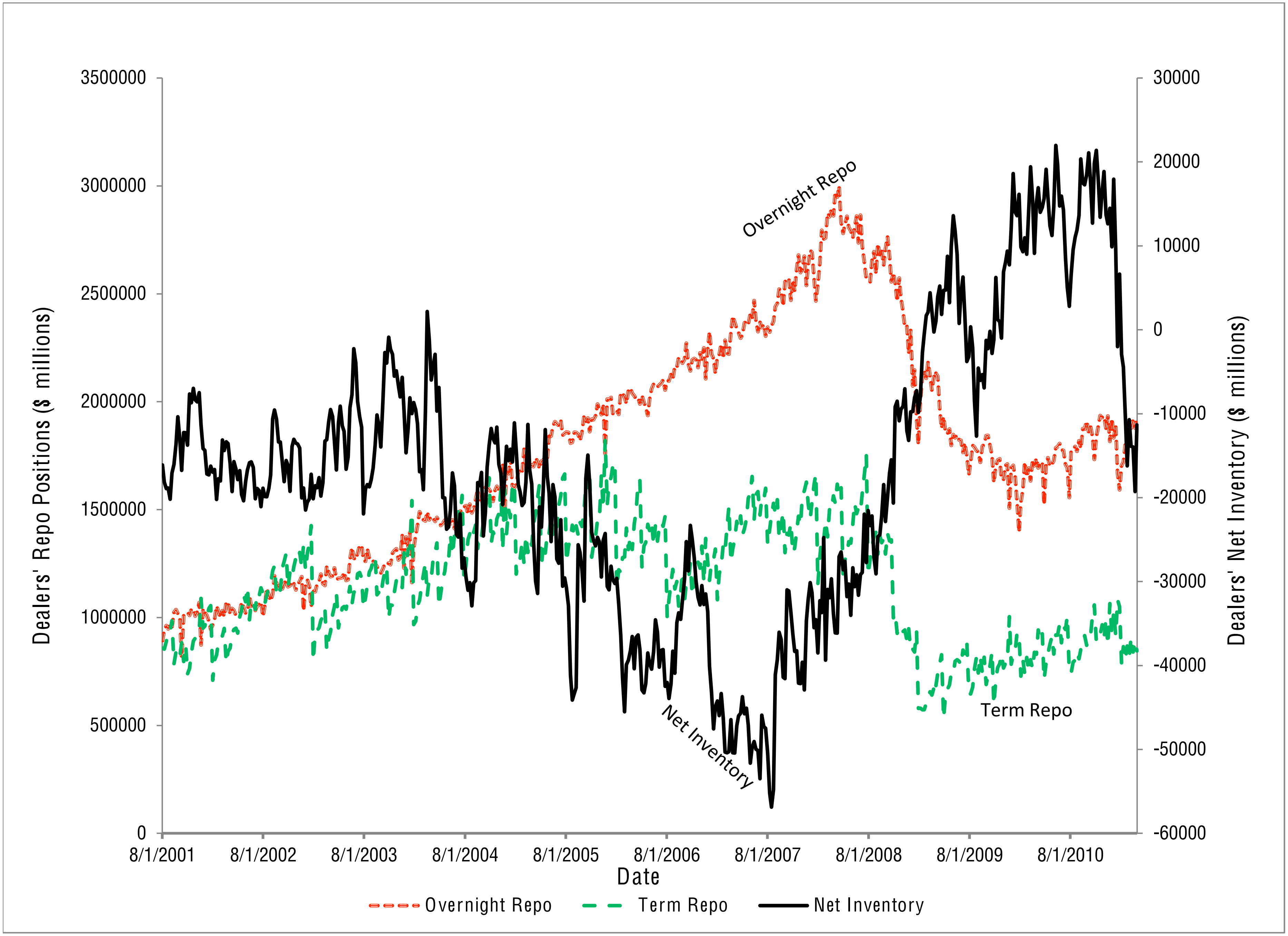

Figure 3. Weekly primary dealers' overnight and term repo positions, and net inventory in US Treasury securities. This graph depicts primary dealers': a) overnight and term repo positions in US Treasury securities on the left vertical axis, and b) net inventory of US Treasury coupon-paying securities with 6-11 years to maturity on the right vertical axis. The data are recorded on weekly basis over the period July 2001 through March 2011. Source: Federal Reserve Bank of New York, http://www.newyorkfed.org/markets/statrel.html

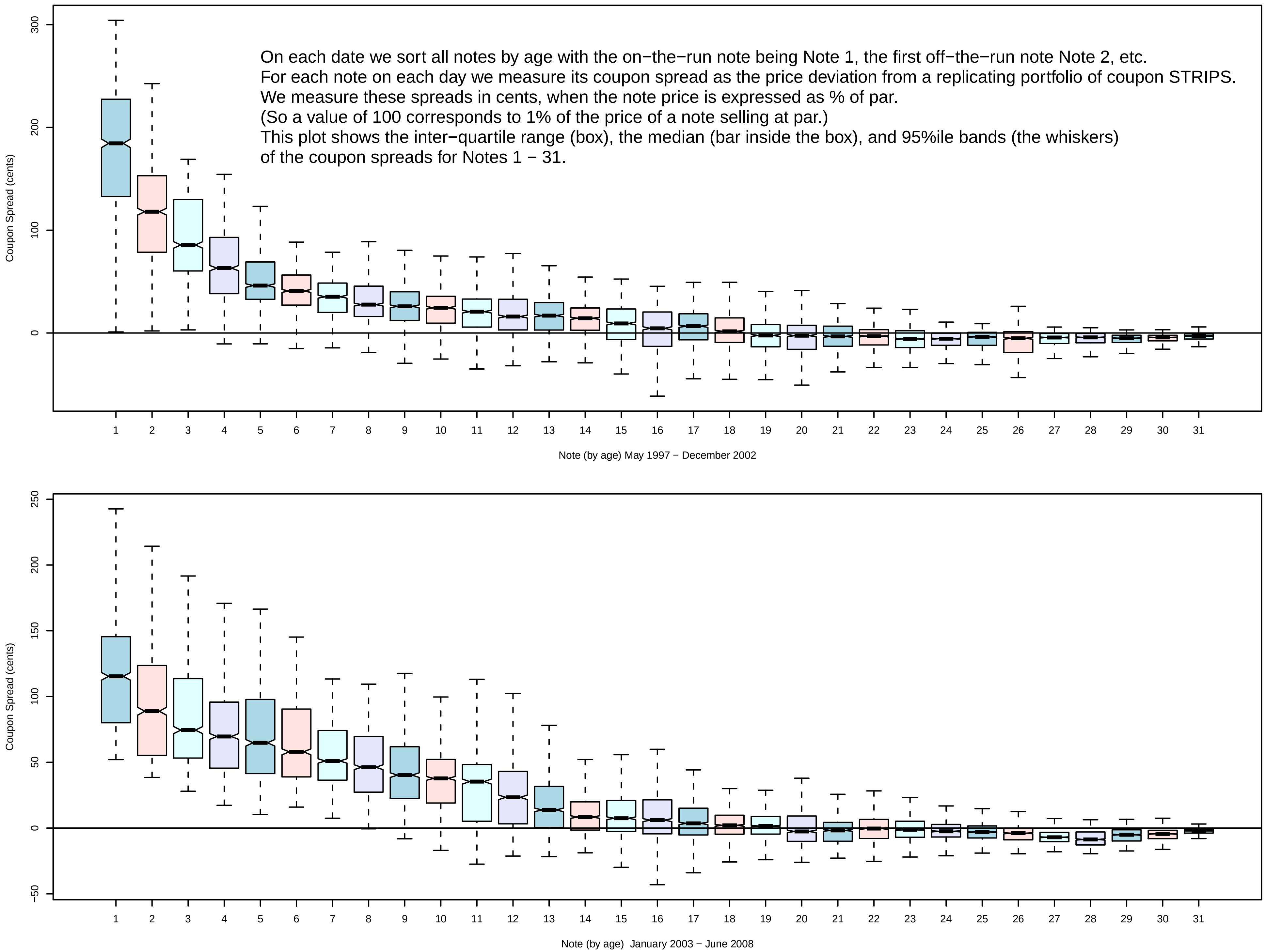

Figure 4a. Cross-section of coupon spreads. This graph depicts sample statistics of coupon spreads on the 31 youngest 10-year US Treasury notes, in cents per $100 par value. The top panel covers the period May 1997 through December 2002. The bottom panel covers the period January 2003 through June 2008.

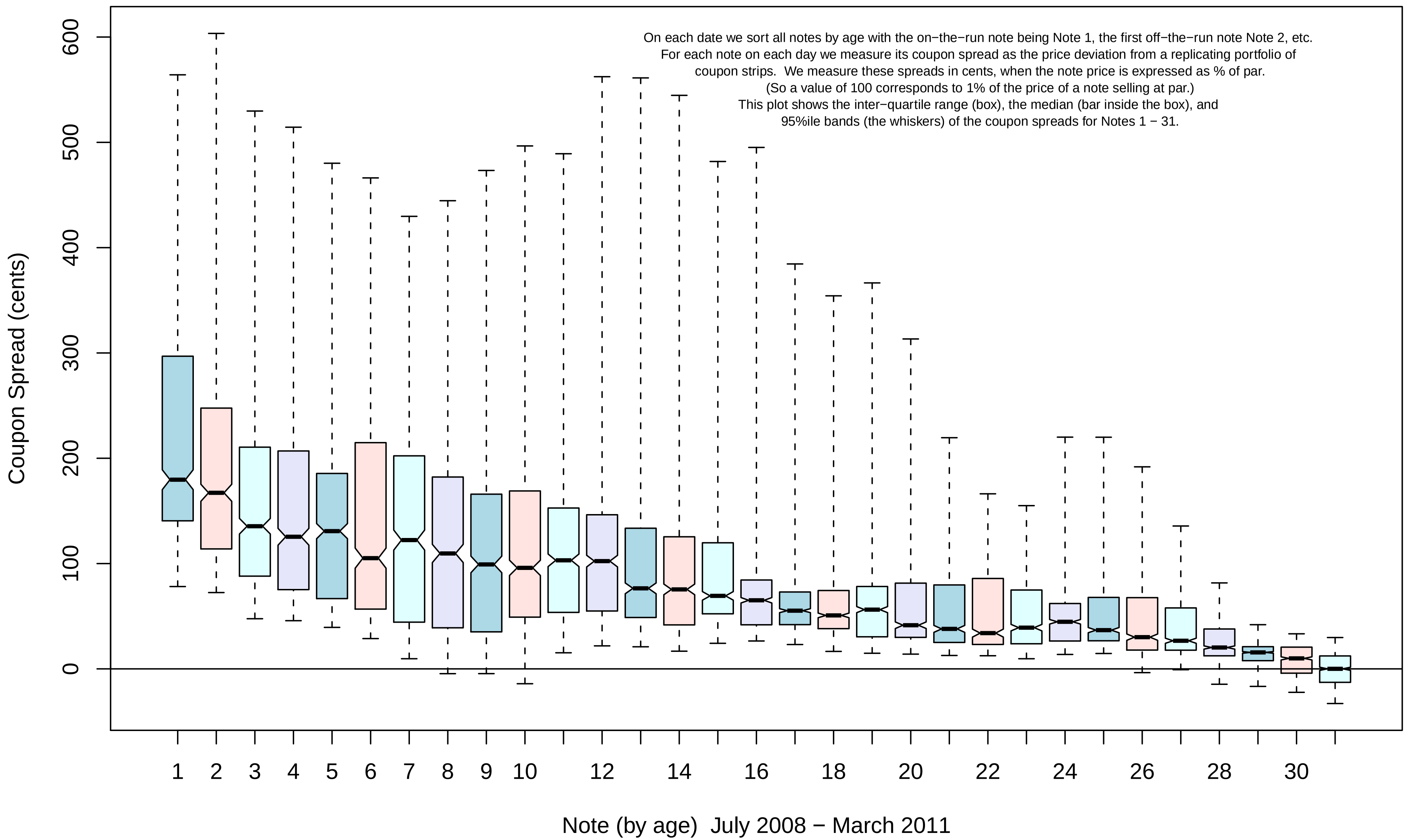

Figure 4b. Cross-section of coupon spreads. This graph depicts sample statistics of coupon spreads on the 31 youngest 10-year US Treasury notes, in cents per $100 par value. This panel covers the period July 2008 through March 2011.

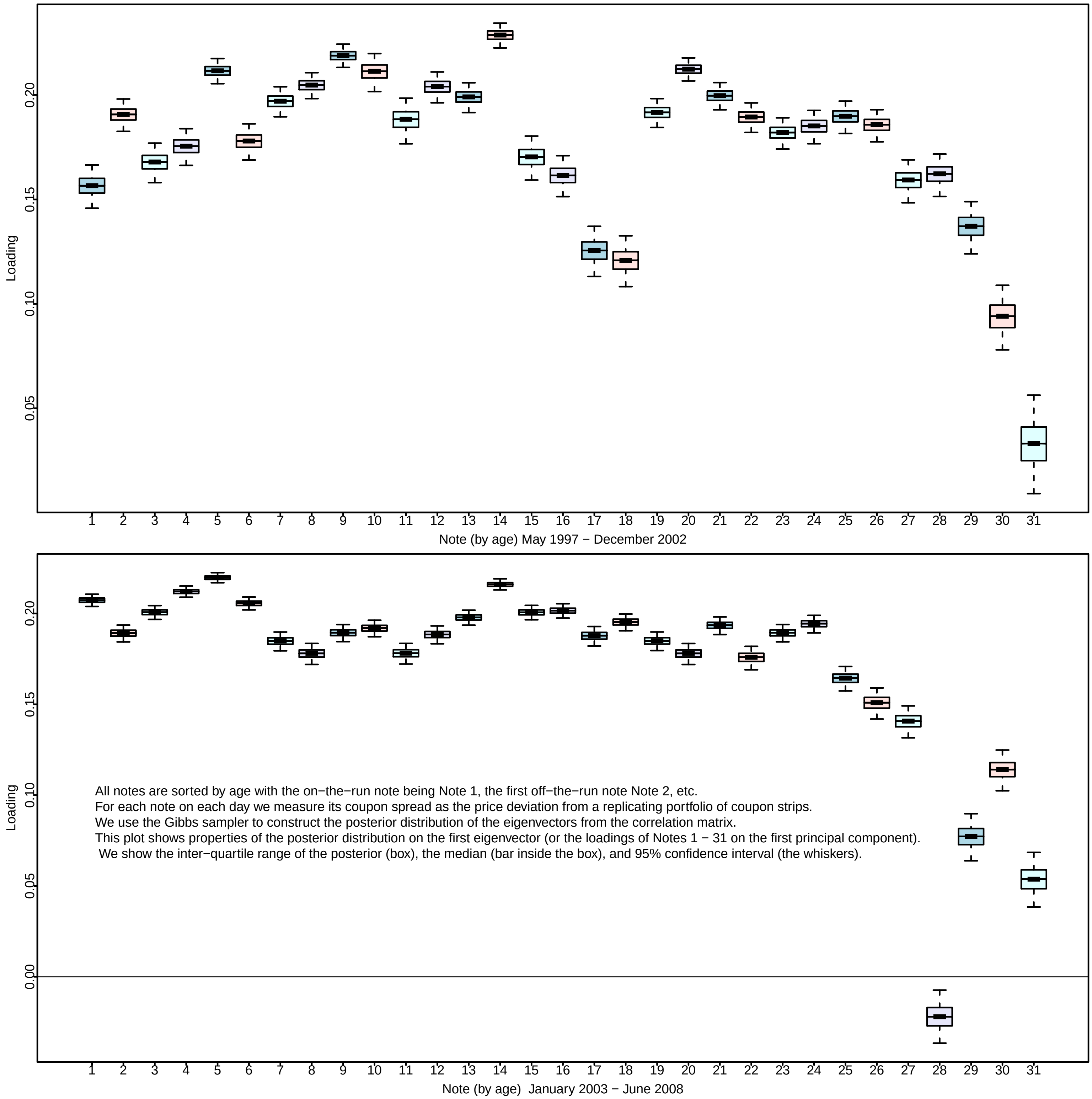

Figure 5a. Loadings on the first principal component of coupon spreads. This graph depicts summary statistics of the posterior distribution of the first eigenvector from the correlation matrix of coupon spreads on the youngest 31 10-year US Treasury notes (i.e., the loadings on the first factor). The top panel covers the period May 1997 through December 2002. The bottom panel covers the period January 2003 through June 2008.

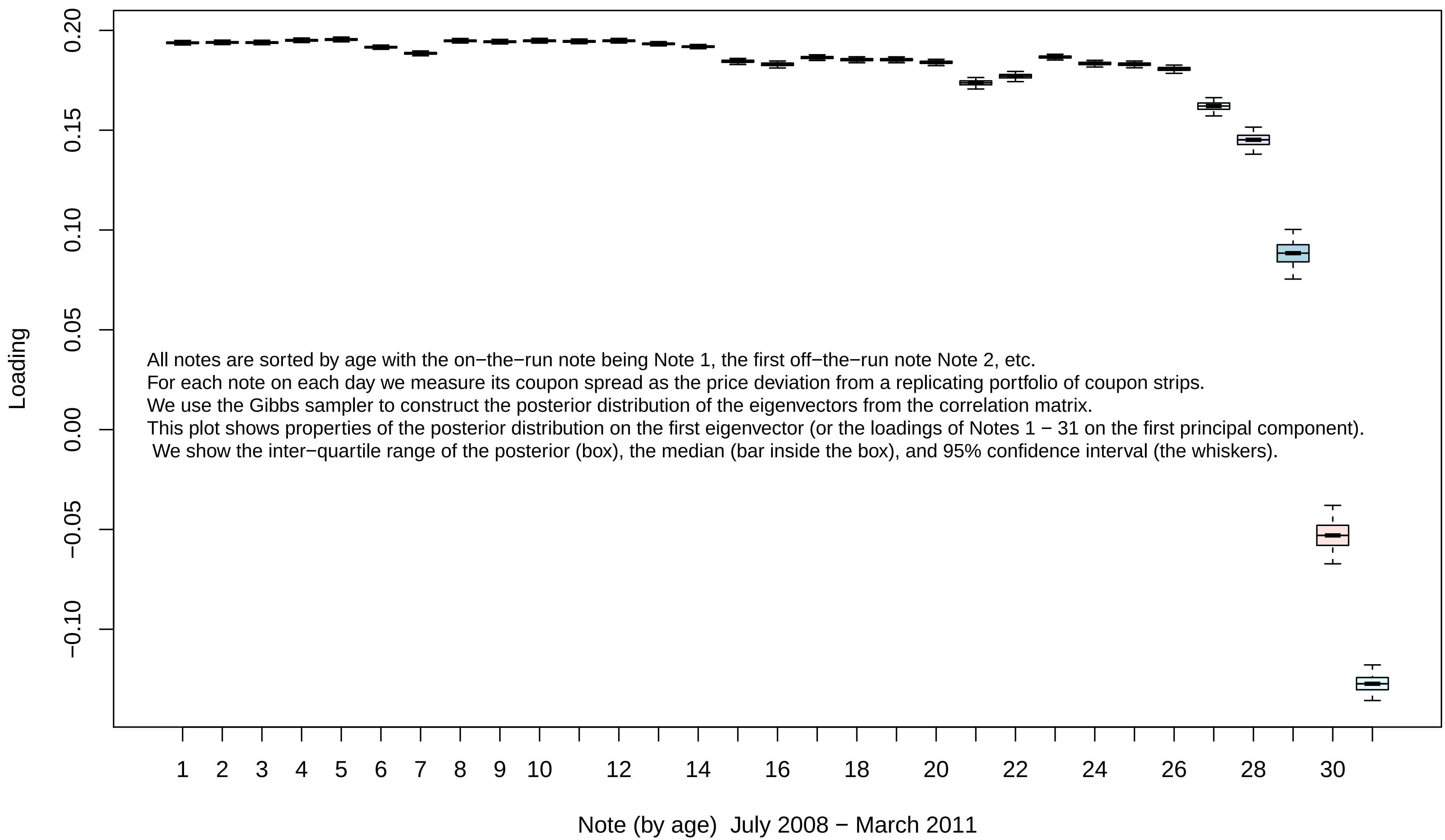

Figure 5b. Loadings on the first principal component of coupon spreads. This graph depicts summary statistics of the posterior distribution of the first eigenvector from the correlation matrix of coupon spreads on the youngest 31 10-year US Treasury notes (i.e., the loadings on the first factor). This panel covers the period July 2008 through March 2011.

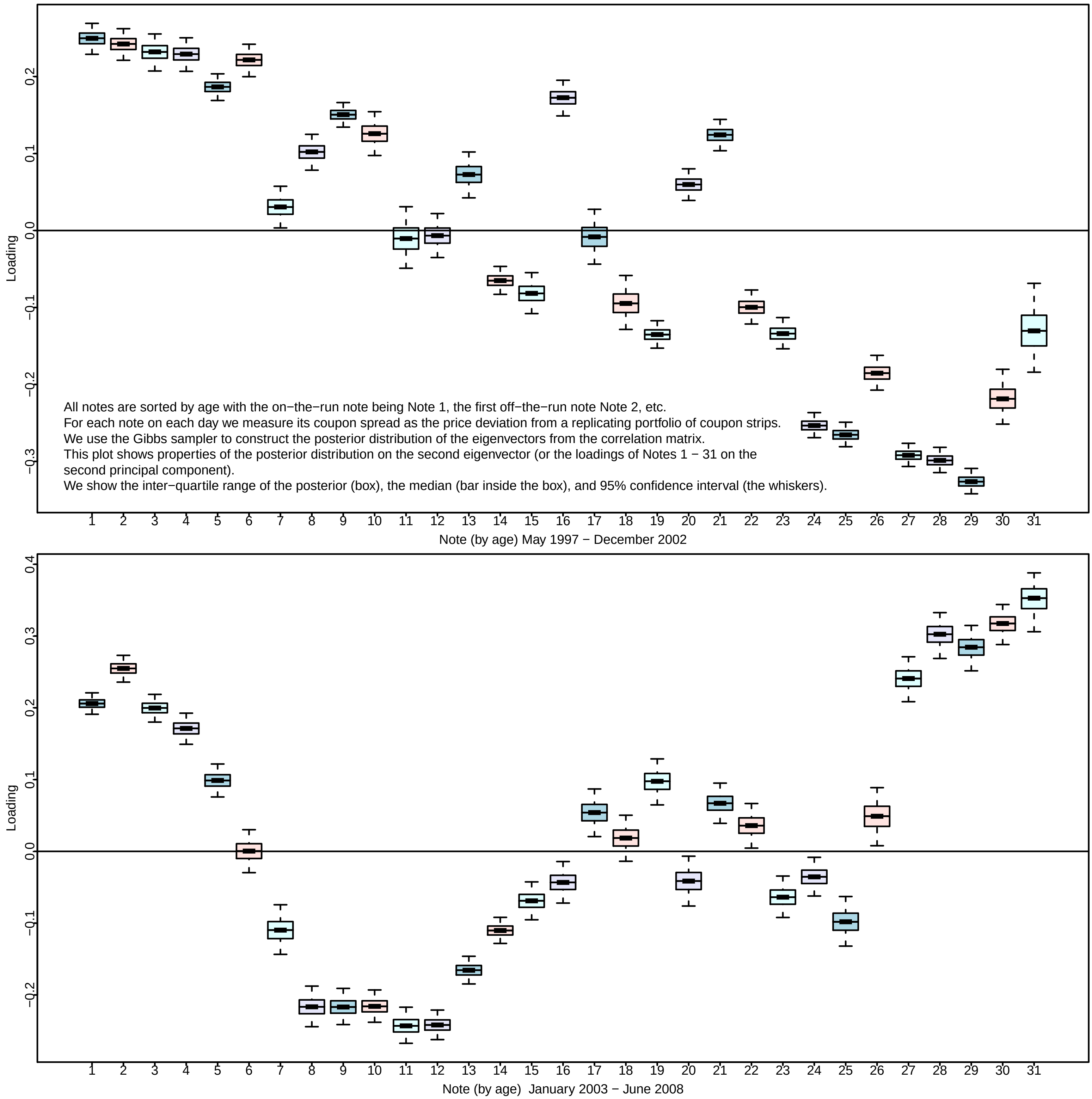

Figure 6a. Loadings on the second principal component of coupon spreads. This graph depicts summary statistics of the posterior distribution of the second eigenvector from the correlation matrix of coupon spreads on the youngest 31 10-year US Treasury notes (i.e., the loadings on the second factor). The top panel covers the periods May 1997 through December 2002. The bottom panel covers the period January 2003 through June 2008.

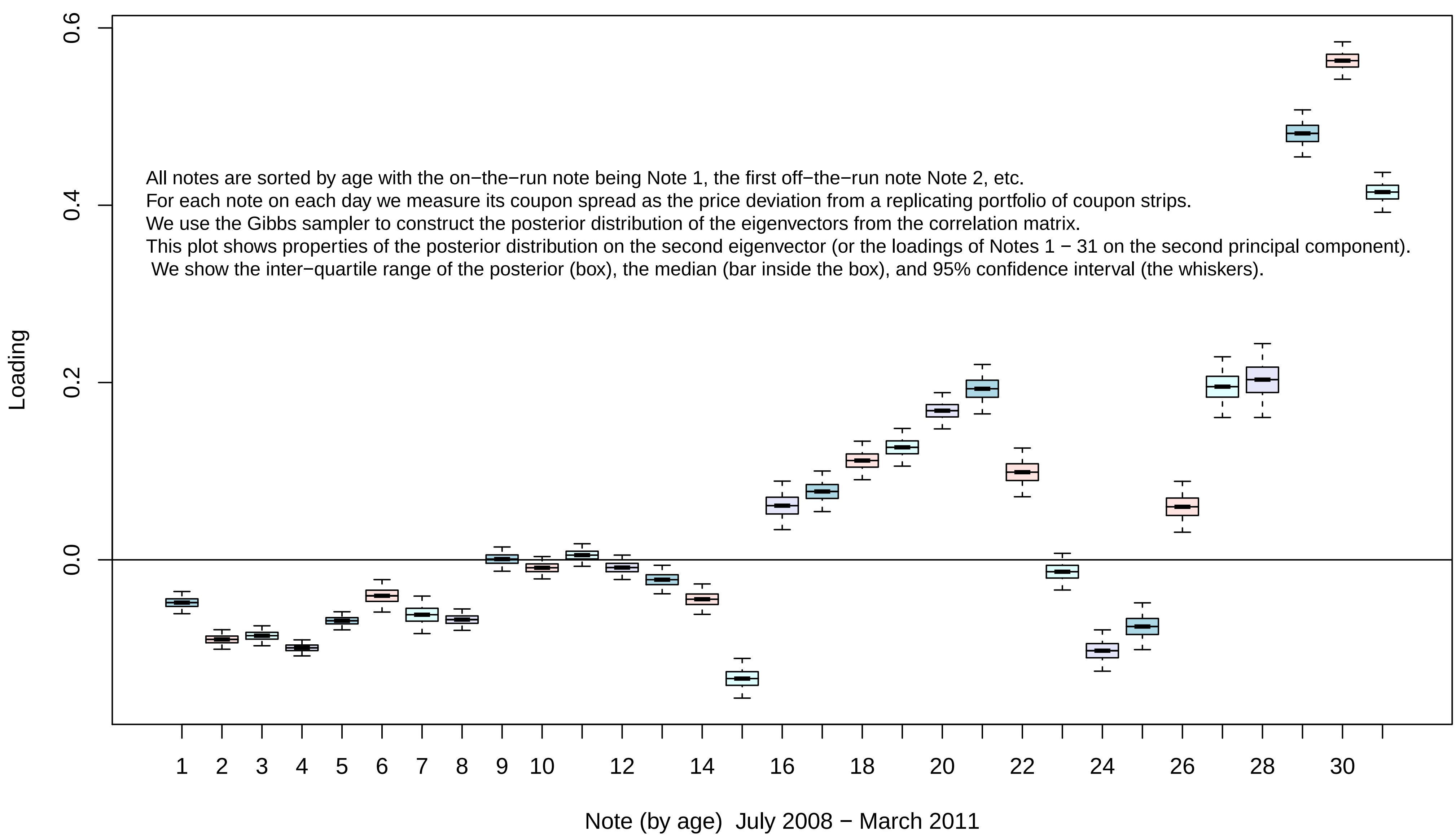

Figure 6b. This graph depicts summary statistics of the posterior distribution of the second eigenvector from the correlation matrix of coupon spreads on the youngest 31 10-year US Treasury notes (i.e., the loadings on the second factor). This panel covers the period July 2008 through March 2011.

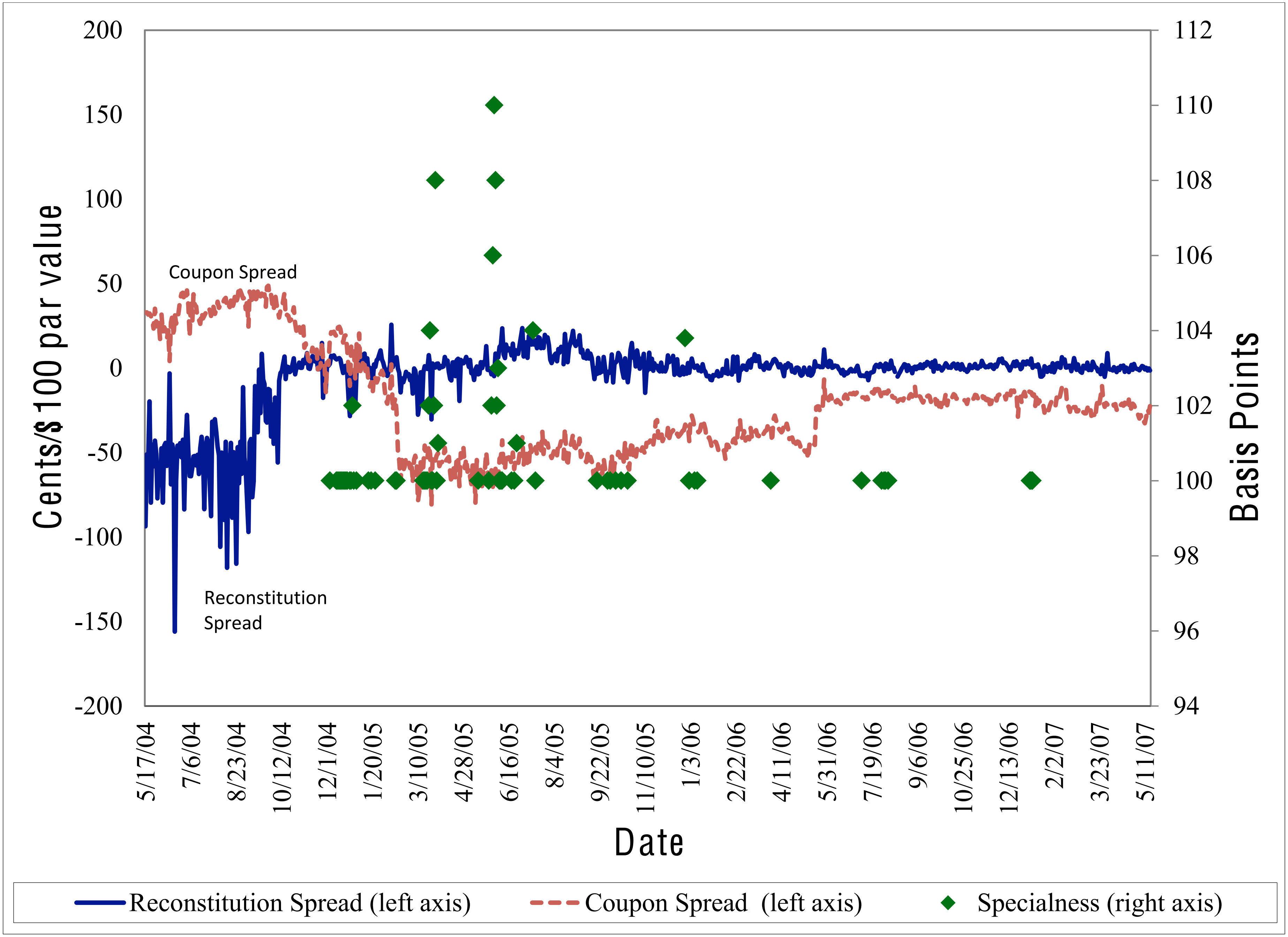

Figure 7. The curious case of the $5\frac{3}{4}\%$ August 2010 note: May 2004 – May 2007. This graph depicts the reconstitution spread, coupon spread, and repo specialness on the August 2010 10-year note over the period May 17, 2004 through May 11, 2007. This is a rare case of prolonged negative coupon spreads (unrelated to the Treasury's buy-back program). Even more curious is the fact that this note trades on special in repo over the same period.

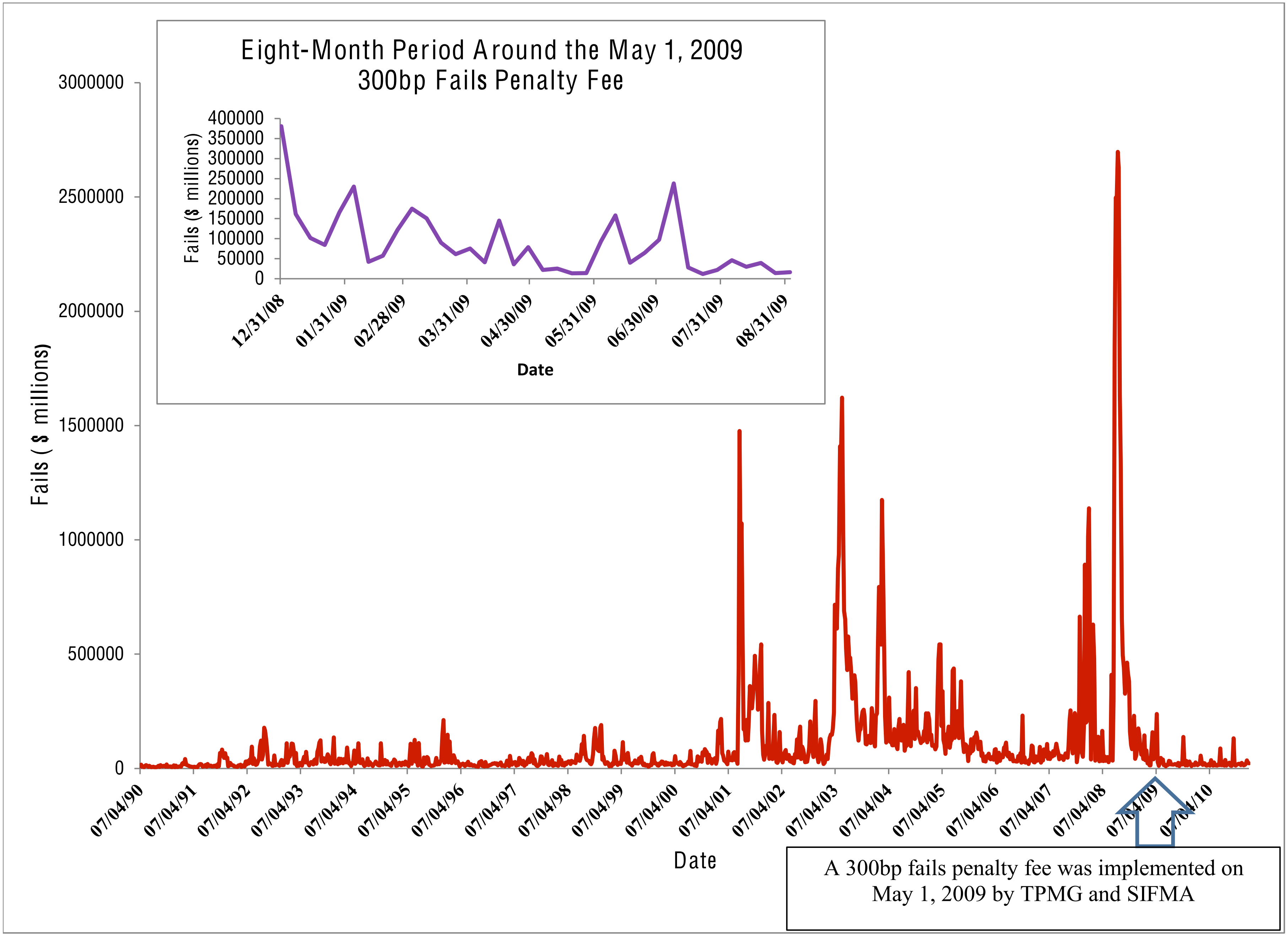

Figure 8. US Treasury Fails to Receive. This graph depicts cumulative weekly fails to receive US Treasury securities in the repurchase market, over the period July 4, 1990 through March 30, 2011. On May 1, 2009 regulators imposed a 300 basis point delivery fails penalty. The inset highlights the 10 months centered on this date, and shows that fails remain relatively high and volatile following the introduction of this penalty.
Data Source: *New York Federal Reserve FR2004 Fails Data.*

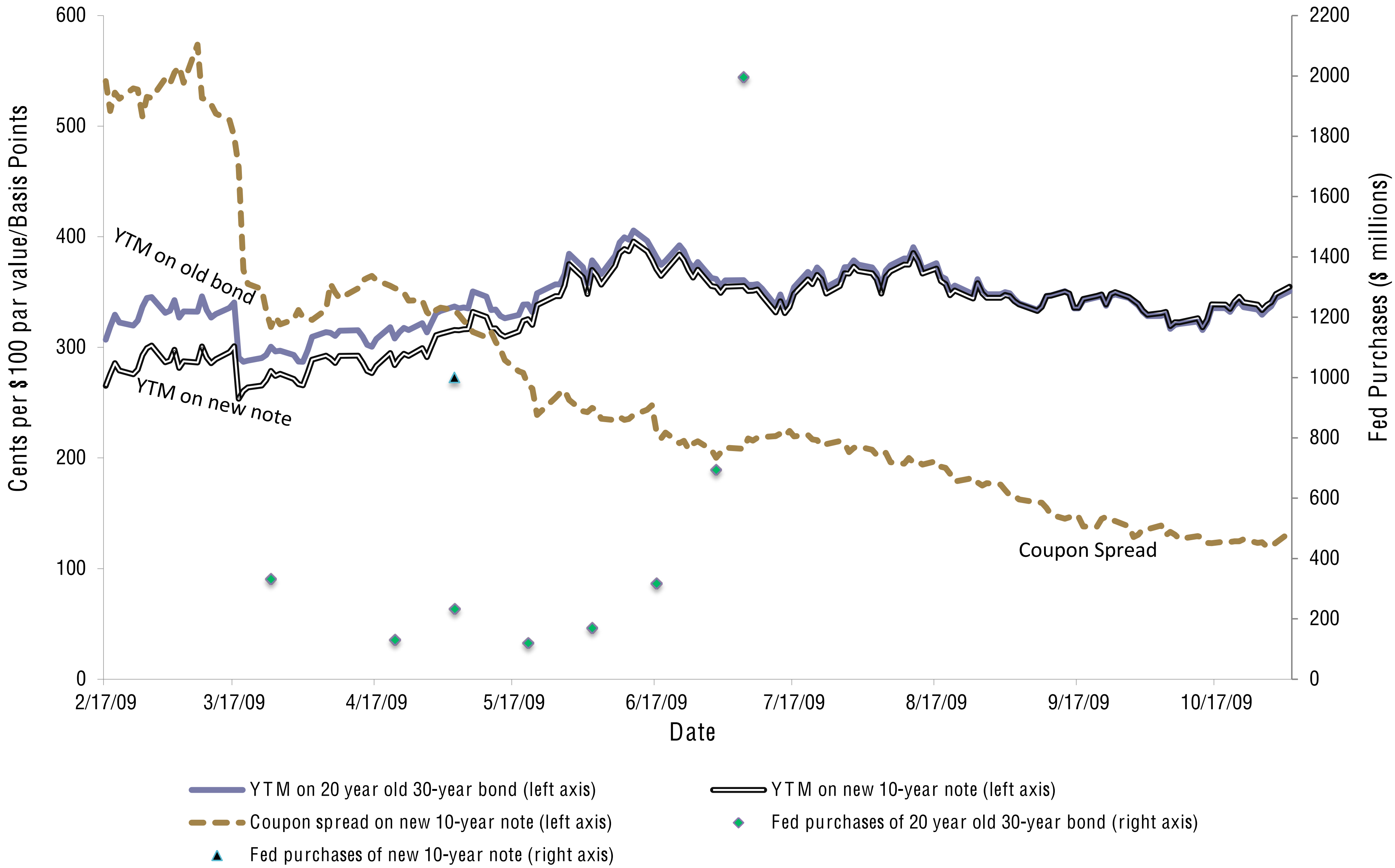

Figure 9. The new 10-year note its 20 year old 30-year bond "twin" and Fed purchases during QE-I. This graph depicts the yield-to-maturity and coupon spread on the February 2019 10-year note for eight months following its opening auction. It also shows the yield-to-maturity on the 20 year old 30-year bond that also expires on February 15, 2019. The figure also shows Federal Reserve purchases of these two securities during the period.

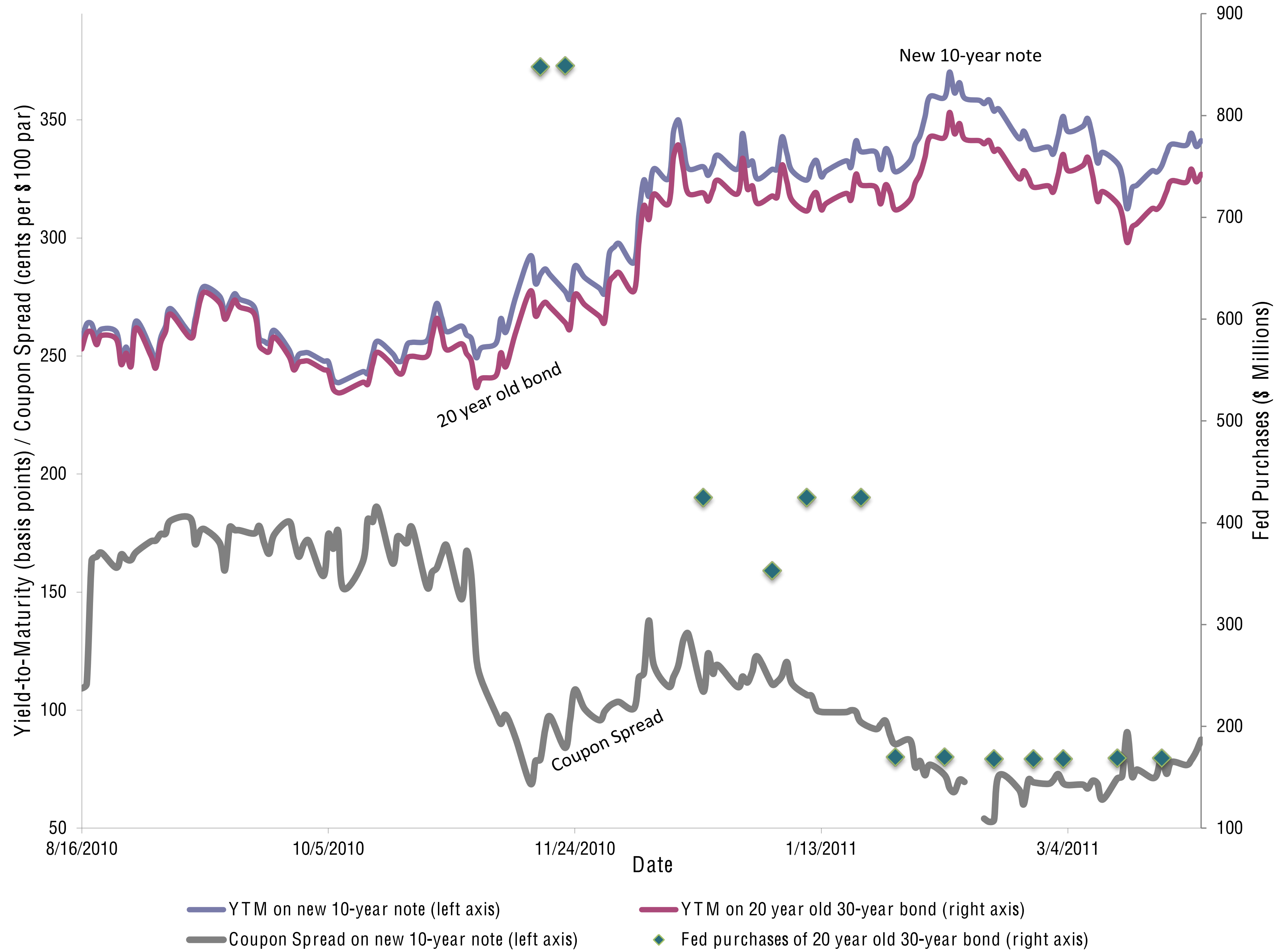

Figure 10. The new 10-year note its 20 year old 30-year bond "twin" and Fed purchases during QE-II. This graph depicts the yield-to-maturity and coupon spread on the August 2020 10-year note for eight months following its opening auction. It also shows the yield-to-maturity on the 20 year old 30-year bond that also expires on August 15, 2020. The figure also shows Federal Reserve purchases of these two securities during the period.

Table I
Summary Statistics for 10-year US Treasury Note Auctions

This table provides summary statistics for all 10-year Treasury note auctions over the period May 1997 through March 2011. Panel A summarizes all auctions in Period 1, May 1997 through December 2002. Panel B summarizes all auctions in Period 2, January 2003 through June 2008. Panel C summarizes all auctions in Period 3, July 2008 through March 2011.

Panel A. May 1997 - December 2002, 24 Auctions

	Mean	Median	Std. Dev.
14 Original Auctions			
Auction Size (total amount, in $ billions)	14.157	13.536	2.246
Bid-to-Cover Ratio	1.97	1.92	0.43
% of Issuance Awarded to Dealers/Brokers	78.4	79.0	10.5
% of Issuance Awarded to Foreigners	7.4	9.5	5.2
0 Reopenings after 1 month			
Auction Size (total amount, in $ billions)	–	–	–
Bid-to-Cover Ratio	–	–	–
% of Issuance Awarded to Dealers/Brokers	–	–	–
% of Issuance Awarded to Foreigners	–	–	–
9 Reopenings after 3 months			
Auction Size (total amount, in $ billions)	11.317	11.460	1.311
Bid-to-Cover Ratio	2.34	2.44	0.26
% of Issuance Awarded to Dealers/Brokers	82.3	80.5	8.8
% of Issuance Awarded to Foreigners	5.6	5.1	3.3
1 Special Reopening			
Auction Size (total amount, in $ billions)	6.000	6.000	0
Bid-to-Cover Ratio	2.36	2.36	0
% of Issuance Awarded to Dealers/Brokers	77.5	77.5	0
% of Issuance Awarded to Foreigners	2.9	2.9	0

Panel B. January 2003 - June 2008, 42 Auctions

	Mean	Median	Std. Dev.
22 Original Auctions			
Auction Size (total amount, in $ billions)	17.163	16.777	2.442
Bid-to-Cover Ratio	2.23	2.27	0.34
% of Issuance Awarded to Dealers/Brokers	61.4	62.0	9.0
% of Issuance Awarded to Foreigners	19.8	16.8	2.4
20 Reopenings after 1 month			
Auction Size (total amount, in $ billions)	9.100	8.000	1.553
Bid-to-Cover Ratio	2.44	2.49	0.38
% of Issuance Awarded to Dealers/Brokers	84.4	84.8	8.0
% of Issuance Awarded to Foreigners	6.4	5.7	6.4
0 Reopenings after 3 months			
Auction Size (total amount, in $ billions)	–	–	–
Bid-to-Cover Ratio	–	–	–
% of Issuance Awarded to Dealers/Brokers	–	–	–
% of Issuance Awarded to Foreigners	–	–	–
0 Special Reopenings			
Auction Size (total amount, in $ billions)	–	–	–
Bid-to-Cover Ratio	–	–	–
% of Issuance Awarded to Dealers/Brokers	–	–	–
% of Issuance Awarded to Foreigners	–	–	–

Table I (Cont'd.)

Summary Statistics for 10-year US Treasury Note Auctions

This table provides summary statistics for all 10-year Treasury note auctions over the period May 1997 through March 2011. Panel A summarizes all auctions in Period 1, May 1997 through December 2002. Panel B summarizes all auctions in Period 2, January 2003 through June 2008. Panel C summarizes all auctions in Period 3, July 2008 through March 2011.

Panel C. July 2008 - March 2011, 35 Auctions

	Mean	Median	Std. Dev.
11 Original Auctions			
Auction Size (total amount, in $ billions)	25.276	25.438	1.872
Bid-to-Cover Ratio	2.68	2.67	0.33
% of Issuance Awarded to Dealers/Brokers	54.1	54.8	12.5
% of Issuance Awarded to Foreigners	24.5	23.2	13.4
11 Reopenings after 1 month			
Auction Size (total amount, in $ billions)	19.502	21.001	2.532
Bid-to-Cover Ratio	2.84	2.77	0.42
% of Issuance Awarded to Dealers/Brokers	61.4	56.2	13.8
% of Issuance Awarded to Foreigners	19.2	16.5	11.3
9 Reopenings after 2 months			
Auction Size (total amount, in $ billions)	20.344	21.006	1.725
Bid-to-Cover Ratio	3.05	3.01	0.37
% of Issuance Awarded to Dealers/Brokers	58.7	56.6	13.4
% of Issuance Awarded to Foreigners	18.5	22.6	8.5
4 Special Reopenings			
Auction Size (total amount, in $ billions)	10	10	0
Bid-to-Cover Ratio	2.00	2.21	0.53
% of Issuance Awarded to Dealers/Brokers	72.2	72.3	8.8
% of Issuance Awarded to Foreigners	5.0	1.6	7.0

Notes:

Between May 1997 and September 2003, the only auction that was not part of the standard quarterly cycle (February, May, August, and November) was the special auction of the 5% August 2011 notes on October 4, 2001, in the aftermath of the attack on the World Trade Center.

From August 2003 through September 2008, the Treasury opened a new note on each quarter in the cycle, and reopened the note after one month.

From November 2008 through March 2011, the Treasury opened a new note on each quarter in the cycle, and reopened the note after one and two months.

Table II

Summary Statistics of Fed Lending Rates (Repo Specialness)

We report summary statistics on specialness (in basis points) for all 10-year Treasury notes over the period April 26, 1999 through March 31, 2011. These data are Federal Reserve overnight lending rates from the New York Federal Reserve's securities lending program.

Notes	No. of Obs.	No. of Obs. on special	No. of Cusips	No. of Cusips on special	Mean (incl. zeros)	Mean Spread above minimum lending rate	Mean (excl. zeros)	Std. Dev. (incl. zeros)	Min. (excl. zeros)	Max. (incl. zeros)
All										
Period 1	28,857	1,007	42	34	6	50	179	38	100	571
Period 2	44,166	3,473	51	45	8	22	102	34	50	515
Period 3	23,739	4,370	43	43	2	4	13	12	1	500
On-the-Run										
Period 1	957	407	10	10	93	89	219	133	100	571
Period 2	1,433	619	23	23	68	73	158	108	50	498
Period 3	689	397	12	12	16	20	28	45	1	316
1st Off-the-Run										
Period 1	957	151	10	8	33	77	208	91	100	506
Period 2	1,433	292	23	22	25	42	122	64	50	515
Period 3	689	152	12	12	3	2	15	11	1	95
2nd Off-the-Run										
Period 1	957	28	10	8	5	56	183	37	100	508
Period 2	1,433	147	23	18	10	20	105	37	50	370
Period 3	689	73	12	8	3	9	32	16	1	175
3rd Off-the-Run										
Period 1	957	20	10	8	3	18	155	23	100	286
Period 2	1,433	117	23	12	9	25	107	36	50	450
Period 3	689	64	12	9	2	3	17	9	1	102
All Deliverable										
Period 1	7,700	644	19	12	17	77	208	67	100	571
Period 2	16,390	2,017	29	29	15	37	121	50	50	515
Period 3	9,234	1,806	24	24	3	6	14	16	1	316

Table II (Cont'd.)

Summary Statistics of Fed Lending Rates (Repo Specialness)

We report summary statistics on specialness (in basis points) for all 10-year Treasury notes over the period April 26, 1999 through March 31, 2011. These data are Federal Reserve overnight lending rates from the New York Federal Reserve's securities lending program.

Notes	No. of Obs.	No. of Obs. on special	No. of Cusips	No. of Cusips on special	Mean (incl. zeros)	Mean Spread above minimum lending rate	Mean (excl. zeros)	Std. Dev. (incl. zeros)	Min. (excl. zeros)	Max. (incl. zeros)
All Deliverable –excluding: –On-the-Run, 1st, 2nd, –and 3rd Off-the-Run										
Period 1	4,045	40	15	8	1	5	132	14	100	286
Period 2	10,934	845	25	24	8	14	97	29	50	416
Period 3	6,534	1,125	20	20	1	1	8	8	1	250
CTD										
Period 1	925	15	15	6	2	9	139	18	100	230
Period 2	1,383	146	19	14	12	31	117	41	50	288
Period 3	547	131	11	10	1	1	6	5	1	95
All Non-Deliverable										
Period 1	21,157	363	42	25	2	2	128	7	100	243
Period 2	27,776	1,456	51	31	4	2	77	18	50	355
Period 3	14,461	2,520	29	29	2	2	12	10	1	500

Notes:

The Federal Reserve data is available at: http://www.newyorkfed.org/markets/securitieslending.html.

Minimum lending rates during the sample period are:

April 26, 1999 (Program Inception) - September 17, 2001: 150 basis points
September 18, 2001 - June 24, 2003: 100 basis points
June 25, 2003 - June 30, 2004: 75 basis points
July 1 2004 - August 20, 2007: 100 basis points
August 21, 2007 - October 7, 2008: 50 basis points
October 8, 2008 - December 17, 2008: 10 basis points
December 18, 2008 - April 6, 2009: 1 basis point
April 7, 2009 - March 31, 2011: 5 basis points.

Table III
Dimensionality Reduction and Coupon Spreads

We report summary statistics from the posterior of the cumulative percentage correlation explained by each of the first three eigenvalues from Principal Components Analysis of the Correlation matrix, and the percentage of total variation explained by the first three factors from Factor Analysis (F3).

Panel A: Period 1 (May 1997 - December 2002)

Model / Component	2.5 %ile	5 %ile	25 %ile	50 %ile	75 %ile	95 %ile	97.5 %ile	Mean	Standard Deviation
PC1	41.3	41.6	42.4	43.1	43.7	44.6	44.9	43.1	0.9
PC2	57.9	58.1	58.8	59.3	59.7	60.4	60.7	59.3	0.8
PC3	66.9	67.1	67.7	68.1	68.5	69.1	69.3	68.1	0.6
F3	71.0	71.1	71.4	71.6	71.8	72.1	72.2	71.6	0.3

Panel B: Period 2 (January 2003 - June 2008)

Model / Component	2.5 %ile	5 %ile	25 %ile	50 %ile	75 %ile	95 %ile	97.5 %ile	Mean	Standard Deviation
PC1	50.9	51.1	52.0	52.6	53.1	54.0	54.3	52.6	0.9
PC2	61.5	61.7	62.4	62.9	63.4	64.1	64.4	62.9	0.8
PC3	67.4	67.6	68.2	68.6	69.1	69.7	69.9	68.6	0.7
F3	78.6	78.7	78.9	79.0	79.1	79.3	79.4	79.0	0.2

Panel C: Period 3 (July 2008 - March 2011)

Model / Component	2.5 %ile	5 %ile	25 %ile	50 %ile	75 %ile	95 %ile	97.5 %ile	Mean	Standard Deviation
PC1	79.8	80.0	80.6	81.0	81.5	82.0	82.3	81.0	0.06
PC2	87.8	87.9	88.4	88.8	89.1	89.6	89.7	88.8	0.05
PC3	91.0	91.1	91.4	91.7	91.9	92.2	92.4	91.7	0.04
F3	96.2	96.3	96.3	96.3	96.4	96.4	96.4	96.3	0.04

Notes:

Principal Components are obtained from the correlation matrix of coupon spreads on the 31 youngest Treasury notes. The time series are plagued by missing data problems (since the Treasury went "off-cycle" with its July and October 1996 auctions). We use a Gibbs sampler, as explained in the appendix to handle the missing data, and to obtain exact posterior distributions of the percentage "explained" by each eigenvalue. We also estimate a 3-factor model, using the Gibbs sampler and the identification scheme of Geweke and Zhou (1996), as explained in the appendix.

Table IV

Posterior Distribution of the Percentage of Total Variance of Coupon Spreads Explained by 3 Factors from Factor Analysis

We report properties of the posterior distributions of functions from Factor Analysis. We estimate a 3-factor model on 31 coupon spreads using the Gibbs sampler and the Geweke and Zhou (1996) identification scheme. At each draw from the sampler, we measure the percentage of the total variance in each coupon spread that is explained by the factors. (This is independent of the data ordering.)

	Period 1			**Period 2**			**Period 3**		
Note	2.5 %ile	Median	97.5 %ile	2.5 %ile	Median	97.5 %ile	2.5 %ile	Median	97.5 %ile
1	75.1	75.8	77.8	81.8	83.4	84.7	94.4	95.0	95.5
2	93.9	95.0	95.9	83.4	85.0	86.4	96.3	96.7	97.1
3	71.4	73.8	76.0	81.0	82.5	84.0	96.7	97.1	97.4
4	67.4	70.2	72.6	90.2	91.2	92.1	98.3	98.5	98.7
5	72.8	75.1	77.1	90.5	91.4	92.3	97.8	98.0	98.2
6	62.1	65.2	68.0	78.7	80.6	82.2	97.5	97.8	98.1
7	43.3	47.8	51.8	72.3	74.7	76.9	96.1	96.6	97.0
8	56.3	59.8	62.9	68.2	71.0	73.6	97.7	98.0	98.2
9	73.7	76.2	78.5	82.5	84.5	86.2	95.9	96.3	96.7
10	70.2	73.8	77.1	71.5	74.0	76.2	96.0	96.4	96.8
11	60.8	65.6	69.9	77.5	79.8	81.9	95.3	95.8	96.2
12	70.4	73.6	76.8	73.3	75.6	77.6	97.3	97.7	97.9
13	78.4	81.8	84.9	70.5	72.8	74.9	97.6	97.9	98.1
14	82.2	84.2	86.1	81.7	83.3	84.7	96.2	96.6	97.0
15	50.0	54.3	58.2	75.1	77.3	79.3	95.0	95.6	96.1
16	45.6	50.1	54.2	81.9	83.8	85.6	96.7	97.2	97.6
17	55.0	60.9	65.9	65.1	68.0	70.6	95.2	95.8	96.3
18	30.3	35.9	40.9	64.4	67.3	69.9	95.8	96.3	96.7
19	50.4	54.2	57.6	55.6	59.1	62.3	96.7	97.2	97.4
20	52.9	56.4	59.7	47.0	51.1	54.8	97.9	98.2	98.5
21	49.7	53.5	57.0	57.6	60.9	63.8	96.7	97.2	97.6
22	48.7	52.9	56.7	48.6	52.6	56.1	82.9	84.7	86.3
23	45.8	49.9	53.7	58.1	61.4	64.4	87.2	88.5	89.7
24	77.4	79.4	81.4	64.6	67.5	70.0	89.9	91.0	92.0
25	83.0	84.7	86.3	47.7	51.9	55.7	87.2	88.5	89.7
26	66.0	68.9	71.6	51.5	55.7	59.6	78.7	81.0	82.9
27	75.8	77.9	79.8	46.9	51.5	55.6	65.0	68.6	71.8
28	80.3	82.2	84.0	12.7	19.3	25.2	42.6	48.6	53.7
29	79.9	81.8	83.6	14.3	20.8	26.7	32.0	39.2	45.3
30	47.4	52.9	58.1	35.3	40.5	45.2	55.5	60.3	64.5
31	6.1	13.9	21.6	18.0	25.3	32.0	58.4	62.8	66.6

Table V
Correlations between *Noise* and Scores from Principal Components Analysis and Factor Analysis

We report properties of the posterior distributions of functions from principal components analysis and factor analysis of coupon spreads. We extract the principal component scores (realizations of the eigenvalues) from the correlation matrix of the 31 most recent 10-year Treasury notes, from three periods, May 1997 – December 2002; January 2003 – June 2008; and July 2008 – March 2011. Rows designated PC1 - PC3 report the correlations between the first through third principal component scores, respectively and Hu, Pan, and Wang's (2012) *Noise* measure. R^2 is the coefficient of determination in a regression of *Noise* on the first three principal component scores. F1-N and F1-S are the correlations between the first factor from factor analysis and *Noise* when the data ordering is standard and re-ordered, respectively, as described in the appendix.

Panel A: Period 1, May 1997 – December 2002.

Variable	Mean	Standard Deviation	1 %ile	2.5 %ile	5 %ile	25 %ile	50 %ile	75 %ile	95 %ile	97.5 %ile	99 %ile
PC1	30.8	0.4	29.9	30.0	30.1	30.5	30.8	31.1	31.5	31.6	31.8
PC2	-40.0	1.2	-42.6	-42.2	-41.9	-40.8	-40.1	-39.3	38.0	-37.6	-37.1
PC3	-1.9	3.4	-9.7	-8.5	-7.4	-4.2	-1.9	0.4	3.8	5.0	6.5
R^2	25.7	0.6	24.3	24.5	24.7	25.3	25.7	26.1	26.6	26.8	27.0
F1-N	50.8	0.59	49.4	49.6	49.8	50.4	50.8	51.2	51.8	51.9	52.2
F1-S	50.4	0.65	48.9	49.1	49.4	50.0	50.4	50.9	51.5	51.7	51.9

Panel B: Period 2, January 2003 – June 2008.

Variable	Mean	Standard Deviation	1 %ile	2.5 %ile	5 %ile	25 %ile	50 %ile	75 %ile	95 %ile	97.5 %ile	99 %ile
PC1	83.4	0.1	83.2	83.2	83.3	83.4	83.4	83.5	83.6	83.6	83.7
PC2	1.6	2.5	-4.2	-3.3	-2.5	-0.1	1.6	3.3	5.7	6.5	7.4
PC3	-27.2	2.3	-32.5	-31.6	-31.0	-28.8	-27.2	-25.6	-23.3	-22.6	-21.8
R^2	77.1	0.5	75.8	76.0	76.2	76.8	77.1	77.4	77.9	78.0	78.1
F1-N	74.4	0.62	73.0	73.2	73.4	74.0	74.5	74.9	75.5	75.6	75.8
F1-S	66.9	0.93	64.7	65.0	65.4	66.3	66.9	67.5	68.4	68.7	69.0

Panel C: Crisis Period, July 2008 – March 2011.

Variable	Mean	Standard Deviation	1 %ile	2.5 %ile	5 %ile	25 %ile	50 %ile	75 %ile	95 %ile	97.5 %ile	99 %ile
PC1	94.0	0.04	93.9	94.0	94.0	94.0	94.0	94.1	94.1	94.1	94.1
PC2	-22.5	3.80	-31.2	-29.9	-28.8	-25.1	-22.5	-20.0	-16.3	-15.1	-13.7
R^2	94.7	0.70	93.4	93.5	93.6	94.1	94.8	95.4	95.7	95.8	95.8
F1-N	95.0	0.20	94.6	94.6	94.7	94.9	95.0	95.2	95.4	95.4	95.5
F1-S	90.0	0.20	89.5	89.6	89.6	89.8	90.0	90.1	90.3	90.4	90.4

Notes: Principal Components are obtained from the correlation matrix of coupon spreads on the 31 youngest Treasury notes. The time series are plagued by missing data problems (since the Treasury went "off-cycle" with its July and October 1996 auctions). We use a Gibbs sampler, as explained in the appendix to handle the missing data, and to obtain exact posterior distributions of functions of the principal components, such as the realization of the eigenvalue on each date (principal component score). The third eigenvalue is not well-identified in the crisis period (as it accounts for less than 4% of the total covariation in coupon spreads).

Table VI
Correlations between the On-the-Run Premium and Scores from Principal Components Analysis and Factor Analysis

We report properties of the posterior distributions of functions from principal components analysis and factor analysis of coupon spreads. We extract the principal component scores (realizations of the eigenvalues) from the correlation matrix of the 31 most recent 10-year Treasury notes, from three periods, May 1997 – December 2002; January 2003 – June 2008; and July 2008 – March 2011. Rows designated PC1 - PC3 report the correlations between the first through third principal component scores, respectively and the on-the-run premium (defined as the difference between the coupon spreads of the on-the-run and first off-the-run notes). R^2 is the coefficient of determination in a regression of *Noise* on the first three principal component scores. F1-N and F1-S are the correlations between the first factor from factor analysis and the on-the-run premium when the data ordering is standard and re-ordered, respectively, as described in the appendix.

Panel A: Period 1, May 1997 – December 2002.

Variable	Mean	Standard Deviation	1 %ile	2.5 %ile	5 %ile	25 %ile	50 %ile	75 %ile	95 %ile	97.5 %ile	99 %ile
PC1	-18.1	0.4	-19.0	-18.9	-18.8	-18.4	-18.1	-17.9	-17.5	-17.4	-17.2
PC2	-8.8	0.9	-10.9	-10.6	-10.3	-9.4	-8.8	-8.2	-7.3	-7.0	-6.6
PC3	7.4	1.9	2.9	3.7	4.3	6.2	7.4	8.7	10.5	11.1	11.8
R^2	4.7	0.3	4.0	4.1	4.2	4.4	4.6	4.9	5.2	5.4	5.5
F1-N	-10.0	0.8	-11.8	-11.5	-11.3	-10.5	-10.0	-9.4	-8.6	-8.4	-8.0
F1-S	-11.8	0.8	-13.6	-13.4	-13.1	-12.4	-11.8	-11.3	-10.5	-10.2	-10.0

Panel B: Period 2, January 2003 – June 2008.

Variable	Mean	Standard Deviation	1 %ile	2.5 %ile	5 %ile	25 %ile	50 %ile	75 %ile	95 %ile	97.5 %ile	99 %ile
PC1	15.5	0.3	14.8	14.9	15.0	15.3	15.5	15.7	16.0	16.1	16.2
PC2	-17.6	1.4	-20.9	-20.4	-19.9	-18.5	-17.6	-16.6	-15.3	-14.8	-14.3
PC3	8.9	1.2	6.3	6.7	7.1	8.2	8.9	9.7	10.9	11.4	11.9
R^2	8.9	1.2	6.3	6.7	7.1	8.2	8.9	9.7	10.9	11.4	11.9
F1-N	-1.4	0.6	-2.9	-2.7	-2.5	-1.9	-1.4	-1.0	-0.4	-0.2	0.0
F1-S	4.4	0.7	2.7	3.0	3.2	3.9	4.4	4.9	5.6	5.8	6.0

Panel C: Crisis Period, July 2008 – March 2011.

Variable	Mean	Standard Deviation	1 %ile	2.5 %ile	5 %ile	25 %ile	50 %ile	75 %ile	95 %ile	97.5 %ile	99 %ile
PC1	-22.2	0.1	-22.4	-22.4	-22.4	-22.3	-22.3	-22.2	-22.0	-21.9	-21.9
PC2	28.8	1.3	25.7	26.2	26.6	27.9	28.8	29.6	30.8	31.2	31.6
R^2	19.2	6.4	12.5	12.8	13.0	14.0	16.5	23.1	32.8	33.6	34.3
F1-N	-23.4	0.5	-24.5	-24.3	-24.1	-23.7	-23.4	-23.0	-22.6	-22.4	-22.2
F1-S	-15.5	0.4	-16.5	-16.3	-16.2	-15.8	-15.5	-15.2	-14.8	-14.7	-14.5

Notes: Principal Components are obtained from the correlation matrix of coupon spreads on the 31 youngest Treasury notes. The time series are plagued by missing data problems (since the Treasury went "off-cycle" with its July and October 1996 auctions). We use a Gibbs sampler, as explained in the appendix to handle the missing data, and to obtain exact posterior distributions of functions of the principal components, such as the realization of the eigenvalue on each date (principal component score). The third eigenvalue is not well-identified in the crisis period (as it accounts for less than 4% of the total covariation in coupon spreads).

Table VII
Correlations between Net Dealer Inventory and Scores from Principal Components Analysis and Factor Analysis

We report properties of the posterior distributions of functions from principal components analysis and factor analysis of coupon spreads. We extract the principal component scores (realizations of the eigenvalues) from the correlation matrix of the 31 most recent 10-year Treasury notes, from two periods, January 2003 – June 2008, and July 2008 – March 2011. Net dealer inventory of 6-11 year nominal Treasury coupon-paying securities is available on a weekly basis from the New York Fed, starting on July 4, 2001. Rows designated PC1 - PC3 report the correlations between the first through third principal component scores, respectively and net dealer inventory (shown graphically in Figure 3). R^2 is the coefficient of determination in a regression of net dealer inventory on the first three principal component scores. F1-N and F1-S are the correlations between the first factor from factor analysis and net dealer holdings when the data ordering is standard and re-ordered, respectively, as described in the appendix.

Panel A: Period 2, January 2003 – June 2008.

Variable	Mean	Standard Deviation	1 %ile	2.5 %ile	5 %ile	25 %ile	50 %ile	75 %ile	95 %ile	97.5 %ile	99 %ile
PC1	35.7	0.2	35.1	35.2	35.3	35.6	35.7	35.9	36.1	36.2	36.3
PC2	43.3	2.1	38.1	39.0	39.7	41.8	43.3	44.7	46.8	47.4	48.2
PC3	48.3	4.1	37.6	39.7	41.2	45.7	48.4	51.1	54.7	55.8	57.1
R^2	60.0	2.8	48.2	49.8	51.0	54.3	56.2	57.9	60.1	60.8	61.5
F1-N	-15.6	1.2	-18.2	-17.8	-2.5	-16.4	-15.6	-14.8	-13.7	-13.3	-12.8
F1-S	-34.4	1.2	-37.2	-36.8	-36.4	-35.2	-34.5	-33.7	-32.6	-32.2	-31.8

Panel B: Crisis Period, July 2008 – March 2011.

Variable	Mean	Standard Deviation	1 %ile	2.5 %ile	5 %ile	25 %ile	50 %ile	75 %ile	95 %ile	97.5 %ile	99 %ile
PC1	-29.6	0.1	-29.8	-29.7	-29.7	-29.6	-29.6	-29.5	-29.4	-29.4	-29.3
PC2	50.6	1.2	47.6	48.1	48.5	49.8	50.6	51.4	52.5	52.8	53.2
R^2	34.3	0.3	33.5	33.6	33.7	34.1	34.3	34.5	34.8	34.9	35.0
F1-N	53.5	0.7	51.8	52.0	52.3	53.0	53.5	54.0	54.7	54.9	55.2
F1-S	43.5	0.7	41.9	42.1	42.4	43.0	43.5	43.9	44.6	44.8	45.1

Notes: Principal Components are obtained from the correlation matrix of coupon spreads on the 31 youngest Treasury notes. The time series are plagued by missing data problems (since the Treasury went "off-cycle" with its July and October 1996 auctions). We use a Gibbs sampler, as explained in the appendix to handle the missing data, and to obtain exact posterior distributions of functions of the principal components, such as the realization of the eigenvalue on each date (principal component score). The third eigenvalue is not well-identified in the crisis period (as it accounts for less than 4% of the total covariation in coupon spreads).