THE TERM STRUCTURE OF BOND MARKET LIQUIDITY

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Abstract

Previous studies of Treasury market illiquidity span short time-periods and focus on particular maturities. In contrast, we study the joint time-series of illiquidity for different maturities over an extended time sample. We also compare time series determinants of on-the-run and off-the-run illiquidity. Illiquidity increases and the difference between spreads of long- and short-term bonds significantly widens during recessions, suggesting a "flight to liquidity" phenomenon wherein investors shift into the more liquid short-term bonds during economic contractions. We also document that macroeconomic variables such as inflation and federal fund rates forecast off-the-run illiquidity significantly but have only modest forecasting ability for on-the-run illiquidity. Bond returns across all maturities are forecastable by off-the-run short-term illiquidity but not by illiquidity of other maturities or by on-the-run bond illiquidity. Thus, short-term off-the-run illiquidity, by reflecting macro shocks first, is the primary source of the liquidity premium in the Treasury bond market.

Introduction

U.S. Treasury Bond Markets are crucial for asset allocation purposes as well as in the setting of benchmark riskless rates used by corporations in capital budgeting. Indeed, average daily trading volume in Treasury markets is about $500 billion, compared to only about $100 billion on the NYSE.[1] This trading activity allows for price discovery, and Brandt and Kavajecz (2004) argue that the extent of price discovery in the Treasury bond is intimately linked to the markets' liquidity. Further, events such as the 1998 bond market turmoil have heightened concerns about bond liquidity crises.[2] Hence, understanding the dynamics of bond market liquidity is of clear academic and practical importance. The attribute of liquidity is also important because it influences expected returns by way of a liquidity premium embedded in bond prices (Amihud, Mendelson, and Pedersen, 2005).

Notwithstanding the importance of understanding liquidity dynamics there remain critical gaps in the literature on bond market liquidity.[3] These lacunae arise because the bond market is not homogeneous but its constituent securities vary by maturity and seasonedness (i.e., on-the-run status). For example, while the presence of a liquidity premium in bond prices was first established for off-the-run bonds (Amihud and

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[1] See http://www.hedgeweek.com/articles/detail.jsp?content_id=238589, quoting a research report by the research firm Celent, and the NYSE 2007 Factbook, respectively.

[2] See the *Wall Street Journal*, "Illiquidity is Crippling the Bond World," (October 19, 1998) p. C1, "Illiquidity means it has become more difficult to buy or sell a given amount of any bond but the most popular Treasury issue. The spread between prices at which investors will buy and sell has widened, and the amounts in which Wall Street firms deal have shrunk across the board for investment grade, high-yield (or junk), emerging market and asset-backed bonds…**The sharp reduction in liquidity has preoccupied the Fed because it is the <u>lifeblood</u> of markets**." (emphasis added).

[3] Studies on bond liquidity include Amihud and Mendelson (1991), Warga (1992), Boudoukh and Whitelaw (1993), Kamara (1994), Krishnamurthy (2002), Goldreich, Hanke and Nath (2004), Fleming (2001), Huang, Cai, and Wang (2002), Fleming and Remolona (1999), Balduzzi, Elton, and Green (2001), and Chordia, Sarkar and Subrahmanyam (2005).

Mendelson, 1991), the previous literature mostly focuses on the dynamics of on-the-run liquidity.[4] Thus, off-the-run liquidity dynamics, which are empirically the most relevant for bond pricing, have not yet been studied. Moreover, while the pricing implications of illiquidity in the stock market have been explored in the time-series[5] and on different cross-sections of stock portfolios,[6] the pricing implications of bond liquidity across different maturities are still unexplored in the literature.

We contribute on both the preceding dimensions by making use of a long time-series of bond liquidity data. The time span of the analysis is important because it allows us to subsume a variety of economic events. As Shiller and Perron (1985) and Shiller (1989) show, increasing the number of observations by sampling more frequently while leaving the total time span of the data unchanged may not increase the power of tests very much.[7] We thus consider an extensive time period that spans November 1967 to December 2005. For this period, we consider the joint dynamics of liquidity and returns across seasonedness and three different maturity classes: short, medium and long.

To our knowledge, there is no previous study that uses such a long time-series and describes the dynamics of liquidity and returns across maturities and on-the-run status within a unified framework. Our analysis allows us to address the following issues, which are as yet un-examined in the literature:

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[4] Fleming and Remolona (1997), (1999), Balduzzi, Elton, and Green (2001), Green (2004), and Chordia, Sarkar and Subrahmanyam (2005)

[5] See Amihud and Mendelson (1986), (1989), Brennan and Subrahmanyam (1996), Amihud (2002), and Jones (2002).

[6] See, Amihud (2002), Pastor and Stambaugh (2003), and Acharya and Pedersen (2005).

[7]If the time series y_t and x_t make long, relatively slow movements through time (a common feature for economic and financial data), then we will need a long time series (spanning many years) before we can measure the true joint tendencies of the two variables. Getting many observations by sampling frequently (say, through weekly or even daily observations) will not give us much power to measure the joint relationship between the two time series if the total time span in which our data are contained is only a few years long. Shiller (1989) stresses the importance of this argument.

- Previous research (Brunnermeier and Pedersen, 2006, and Chordia, Roll, and Subrahmanyam, 2005) suggests that macroeconomic variables and price volatility may impact bond market liquidity by affecting market-making costs. Do such variables differentially impact on- and off-the-run market making costs, and in turn, liquidities?
- Are bond returns forecastable from liquidity levels, i.e., is there evidence of liquidity premia in the bond market?
- How are liquidity shocks transmitted in the bond market? Are they reflected first in the relatively less active off-the-run issues or the more active on-the-run ones?
- If the liquidity of certain bonds forecasts those of other bonds by reflecting liquidity shocks first, then it may forecast returns not just in the own-market but in other markets as well. This is because liquidity levels in the own-market provide information about future liquidity, and liquidity premia in other markets. This leads us to the question: How does the predictive power of liquidity for bond returns vary across maturity and off-the-run status?

We find that liquidity conditions in the bond market are affected by the economic environment. For example, bond spreads increase during recessions. Moreover, the difference between spreads of long- and short-term bonds significantly widens during recessions, suggesting that investors shift funds into short-term bonds during this time, thus creating liquidity. This is consistent with flight-to-quality and flight-to-liquidity phenomena.

Our Granger-causality results indicate that short-term liquidity causes long-term liquidity and that there is no evidence of reverse causality. This indicates that liquidity shocks are transmitted from the short end to the long end. We also find that off-the-run liquidity can be predicted by a larger set of macroeconomic and market variables than on-the-run liquidity. Thus, shocks to inflation and monetary policy tightening, associated with positive shocks to the federal fund rate, increase off-the-run liquidity across all maturities, consistent with the notion that these macroeconomic variables affect order processing and inventory holding costs. However, for on-the-run liquidity, the predictive power of the macro variables is considerably reduced. This is consistent with the notion that active trading in on-the-run bonds mitigates the impact of macro variables on inventory holding costs.

We also find that positive shocks to bond returns across different maturities decrease off-the-run bond liquidity and shocks to volatility increase liquidity. These results are consistent with those for the stock market described by Chordia, Roll, and Subrahmanyam (2001), who show that up-market moves have a positive effect on liquidity, and with models of microstructure which argue that increased volatility, by increasing inventory risk, tends to increase market liquidity (Ho and Stoll, 1983, and O'Hara and Oldfield, 1986).

The liquidity premium has been previously attributed to the yield difference between equivalent instruments but different levels of liquidity. For example, Amihud and Mendelson (1991) compare the yields on Treasury notes and bills with the same time to maturity and find a significant yield differential. Krishnamurthy (2002) studies the price difference between the on-the- run and the most recent off-the-run 30-year bond and concludes that the yield difference results from a demand for liquid assets. Longstaff (2004) compares the yield differential between zero-coupon Treasury and Refcorp bonds and also finds evidence of a large liquidity premium.[8] Most of these studies are limited by short time-spans where high frequency market microstructure data are available.

In contrast to previous literature we look directly at the effect of liquidity on bond returns over the long run in a variety of economic conditions. We use vector autoregression analysis, which allows us to account for joint dynamics between liquidity and returns across different maturities. We find that short-term off-the-run liquidity is priced across returns of short, medium, and long-term bonds while medium and long-term liquidity has no significant impact on prices in a joint dynamic framework. On-the-run liquidity is not priced, either. This finding is consistent with our previous results: short-term bond liquidity is driven by a larger set of economic variables and it transfers the shocks to the liquidity of other maturities. This result is new and it suggests that liquidity of the off-the-run short-term issues is a source of liquidity premium in the Treasury bond market.

The rest of the paper is organized as follows. The next section provides the economic arguments that motivate our study. We describe the data and the liquidity measure in Section II. Section III describes the results of time series analysis of the illiquidity series, economic variables, and bond returns. Section IV concludes.

I. Economic Motivation

This section delineates the questions our data have the opportunity to address. These issues span the behavior of bond liquidity across different states of the macroeconomy, the effect of macroeconomic variables on liquidity, and how the liquidity premium varies across maturities and seasonedness.

[8] See also Warga (1992), Kamara (1994) and Goldreich, Hanke and Nath (2004).

First, the behavior of illiquidity during recessions and expansions is of interest. In particular, lower liquidity during recessions due to increased risk premia (Dumas, 1994) can exacerbate market declines as agents demand higher required rates of return (Amihud and Mendelson, 1986). Our data allow an explicit comparison of illiquidity across different macroeconomic regimes. It also is often suggested (see, e.g., Brunnermeier and Pedersen, 2005) that tighter collateral constraints during recessions may result in a "flight to liquidity" wherein agents flee to more bonds with lower trading costs. Our comparison of illiquidity in off-the-run and on-the-run bonds of different maturities during recessions allows an analysis of this issue.

Next, the impact of macroeconomic variables on the bond market across the term structure spectrum is an unexplored issue. While Chordia, Sarkar, and Subrahmanyam (2005) show that monetary policy impacts financial market liquidity, the issue of whether it is primarily through the demand side (by the actions of traders) or the supply side (because of alterations in dealer financing costs) remains unexplored. We argue that if the impact occurs on the supply side it should be more evident in the less-liquid off-the-run issues because that is where dealers have to hold positions for longer periods, on average. There may also be a tradeoff involving bond maturities. For example, if dealer inventory costs are indeed higher in the off-the-run market, they may be more relevant in those maturities with greater order imbalances because that is where inventory would take on more extreme values. It is possible that short-term off-the-run bonds with more volume may also have more extreme order imbalances. On the other hand, an offsetting effect is that long-term bonds have less volume and thus involve a greater time for which dealer positions must be held. This may increase the influence of macro variables on inventory carrying costs and thus, illiquidity in long-term bonds relative to short-term bonds. Thus, the issue of how the influence of macro information varies across on-the-run status and maturity is an empirical one that we are able to explore.

The preceding arguments also have implications for the nature of the liquidity premium in bond prices. For example, if it is indeed the case that short-term illiquidity reflects macro information first, then, by signaling changes in bond market liquidity and liquidity premia across the term structure spectrum, it may also forecast illiquidity as well as returns for other maturities. By examining the return forecasting ability of various bonds according to their on-the-run status and maturity, we are able to shed light on this issue as well.

II. Basic Statistics

II. A The Data

We measure liquidity in the Treasury market with relative quoted spreads. This is a standard measure for the Treasury market. The simple bid-ask spread measure, based on widely available data, is highly correlated with price impact, which otherwise is difficult to estimate over a long time horizon basis due to data limitations (Fleming, 2003).[9] The quoted bid and ask prices are from the CRSP daily Treasury Quotes file from November 1967 to December 2005.[10] The file includes Treasury fixed income securities of 3 and 6

[9] Chordia, Sarkar, and Subrahmanyam (2002) show that daily correlations between quoted and effective spread changes in the bond market is 0.68 over their nine-year sample period, while their 2005 version shows that daily quoted spreads have a correlation of –0.49 with depth. This indicates that quoted spreads are reasonable liquidity proxies.

[10] In 1996 CRSP switched its data source from the Federal Reserve Bank of New York to GovPX indicative quotes. We address this issue in our robustness checks, described later.

months, 1, 2, 3, 5, 7, 10, 20 and 30 years to maturity. Once issued, the security is considered as *on-the-run* and the older issues are *off-the-ru*n.[11] The quoted spread for the Treasury bond market is computed as

$$QS = \frac{Ask - Bid}{\frac{1}{2}\left(Ask + Bid\right)},$$

where *Ask* and *Bid* are quoted ask and bid prices for a particular day (using only two-sided quotes for the calculation). The monthly average spread is computed for each security and then equally weighted across different assets for each month.

We use six bond liquidity series across three maturity classes and seasonedness status. The first maturity class is short-term liquidity computed for T-bills with maturity less than or equal to 1 year. The second is the liquidity of the medium-maturity assets obtained from the quotes on 2-to-5 year bonds. The third is the liquidity of the 10-year note, a traditional benchmark. We study the three series separately for *on-the-run* and *off-the-run* issues.

II.B The Impact of Recessions

Table 1 provides descriptive statistics for the illiquidity series. For the whole sample (Panel A) the spreads for medium- and long-term bonds tend to be wider for off-the-run issues than the on-the-run bonds. For short-term bonds, spreads of on-the-run issues are on average wider for the whole sample (Panel A). During non-recessions (Panel C), the average spreads of short-term bonds tend to be very close in magnitude for on-the-run and off-the-run issues. However, both short-term on- and off-the-run spreads

[11] This is a standard definition of on-the-run and off-the-run bonds.

increase by more than a factor of two during NBER recessions (Panel B). Medium- and long-term spreads also increase during recessions compared to non-recessions, but the percentage increase is less dramatic than that for short-term bonds. Thus, spreads are higher during recessions and their increase is especially pronounced for short-term maturities.

Table 2 reports the difference between long- and short-term spreads for the whole sample and for sub-samples. The difference is positive, as the spreads are higher for the long-term bonds. For both on-the-run and off-the-run issues the difference is significantly higher during recessions. This suggests that investors may shift into short-term bonds in recessionary periods.[12]

Figures 1 and 2 present graphs for the illiquidity of on-the-run and off-the-run issues, respectively, by maturity. Higher values correspond to higher transactions costs. Gray bars denote NBER recessions. For the on-the-run bonds, as Figure 1 Panel A shows, the illiquidity of short-term bonds almost always increases during recessions. This pattern is less pronounced for long-term bonds, Panel C, and is nearly absent for medium-term bonds, Panel B. In contrast, for off-the-run bonds, Figure 2, an increase in illiquidity during recessions is observed across all maturities. This pattern points toward a heterogeneity in liquidity dynamics across on-the-run and off-the-run bonds, which we explore in detail below.

III. Vector Autoregression Analysis

[12] While it would be of interest to confirm this inference using volume data, such data is not available for the bond market over a long enough sample period.

Our goal is to explore the intertemporal associations between bond illiquidity of different maturities, returns, volatility and macroeconomic variables which affect bond prices and can also have an impact on illiquidity. In particular, we are interested in determining what forces drive the dynamics of illiquidity of on-the-run and off-the-run issues and what relations hold between illiquidity of different maturities and bond returns. We run our analysis separately for on-the-run and off-the-run issues.

III.A The Explanatory Variables

We use adjusted time series of illiquidity after removing a time trend and the square of the time trend. Earlier work (e.g., Chordia, Roll, and Subrahmanyam, 2001), argues that returns may influence future trading behavior, which may, in turn, affect liquidity. For instance, the portfolio-rebalancing arguments of Merton (1971) imply return-dependent investing behavior, and such order imbalances in response to a price change may strain liquidity. Thus, as our first set of explanatory variables, we use returns of three maturity ranges: short, medium, and long. To capture price variation in the short-maturity range, we use the return on 3 month T-bill (RET1). Returns on 5-year and 10-year notes represent medium (RET5) and long (RET10) maturity, respectively. All returns are from the CRSP Treasury monthly file.

In addition, Benston and Hagerman (1974) suggest a role for volatility in causing illiquidity by indicating that increased volatility implies increased inventory risk and hence, a higher bid-ask spread (see Duffie, Gârleanu, and Pedersen, 2007, for a similar argument). We thus include return volatility as an explanatory variable. To measure the volatility in the Treasury market we use the volatility of a 10 year note.[13] The volatility is obtained as monthly standard deviation of daily returns available from CRSP daily Treasury files.

Among other variables, we use inflation, because inflation surprises have a large effect on the level of the entire yield curve (Ang and Piazzesi, 2003). Campbell and Ammer (1993) argue that bond returns are driven largely by news about future inflation. Positive inflation shocks may drain trading activity out of the bond market, reducing liquidity. Such shocks may also signal a shift in future monetary policy (i.e., the expectation that the Federal Reserve may raise interest rates to dampen inflation) and thus can affect liquidity by portending a shift in inventory financing costs. Inflation is obtained as the growth rate in the consumer price index. The data are from the Federal Reserve Bank of St. Louis.

Further, Fama and French (1993) argue that term and default spreads capture a lot of variation in Treasury bond returns. Moreover, term and default spreads as proxies for business cycles can be important drivers of illiquidity since, as Figures 1 and 2 show, spreads tend to widen during economic downturns. We therefore add term and default premiums to the vector of state variables. The term premium (TERM) is defined as the difference between yields on a 10-year T-note and three-month T-bill. The default premium (DEF) is the difference between yields on long-term BAA-rated and AAA-rated bonds.

There are also reasons to expect a strong relationship between monetary policy and illiquidity in our sample. Empirically, there is overwhelming evidence highlighting the effect of macroeconomic news on illiquidity of Treasury bonds for intraday data of on-

[13] Our results do not change if we use the volatility of 5 year bonds.

the-run issues (Fleming and Remolona, 1997, 1999, Balduzzi, Elton, and Green, 2001, and Green, 2004). Also, a loose monetary policy may decrease illiquidity and encourage more trading by making margin loan requirements less costly, and by enhancing the ability of dealers to finance their positions (Chordia, Sarkar and Subrahmanyam, 2005). Monetary conditions may also affect bond prices through their effect on volatility (Harvey and Huang, 2002) and interest rates. Therefore, as indicators of the monetary policy stance, we include the federal funds rate (FED). Since the unit root test indicates nonstationarity in FED, the subsequent analysis uses first differences. The data are from the Federal Reserve Bank of St. Louis.

We use vector autoregression (VAR) analysis to study joint dynamics of the variables.[14] In accordance with the AIC and Schwarz Bayesian Information Criterion, we estimate the VAR with one lag. Table 3 reports pairwise Granger-causality tests between the endogenous variables in the VAR. For the null hypothesis that variable *i* does not Granger-cause variable *j*, we test whether the lag coefficients of *i* are jointly zero when *j* is the dependent variable in the VAR. The cell associated with the i^{th} row variable and the j^{th} column variable shows the Chi-square statistics and corresponding p-values in parentheses.

III.B Granger Causality Tests

The results for illiquidity are presented in Table 3, Panel A. For both on-the-run and off-the-run issues, illiquidity of short-term bonds Granger-causes illiquidity of other maturities. For off-the-run bonds the causality goes in one direction only, while for on-

[14] See Chordia, Sarkar, and Subrahmanyam (2005) for a discussion of why the VAR is appropriate in dynamic analyses of liquidity across markets.

the-run ones, the causality occurs in the reverse direction only for medium-term bonds to short-term bonds. The evidence indicates that illiquidity shocks are largely transmitted from the short end to the long end. Beber, Brandt and Kavajecz (2007) find that liquid Euro-area bonds attract more order flow, presumably both informed and uninformed. This suggests that the illiquidity of short-term bonds, as the most liquid asset class, may reflect information before other maturities. Our results are consistent with this notion.

Panels B and C present the results for causality tests between illiquidity and other endogenous variables for on-the-run and off-the-run issues, respectively. For brevity, we focus on causation involving the liquidity variables. We also find that all four macro variables (DEF, TERM, FED, and INFL) cause short-term off-the-run illiquidity. The last three also cause on-the-run short-term spreads. The impact of these variables on longer-term spreads is a bit mixed. Overall, though, macroeconomic variables do forecast bond market illiquidity, especially at the short-end of the term structure spectrum. We find that volatility has a causality effect only on illiquidity of on-the-run issues. We will re-examine these findings in the next subsection when we present impulse response functions.

For off-the-run bonds, we find that illiquidity of all maturities Granger-causes the return on short-term bonds and volatility. Also, the illiquidity of short-term bonds causes the return of medium-term bonds. The effect of on-the-run illiquidity on bond returns is far less pronounced. Overall, the evidence for off-the-run illiquidity supports the literature on liquidity premium in the Treasury bond markets (Amihud and Mendelson, 1991).

Note that the Granger causality results are based on the analysis of the coefficients from a single equation, and do not account for the joint dynamics implied by the VAR system. A clearer picture can potentially emerge if we use impulse response functions (IRFs). The IRF traces the impact of a one-time, unit standard deviation, positive shock to one variable on the current and future values of the endogenous variables. Since innovations are correlated, they need to be orthogonalized. They are computed using standard Cholesky decompositions of the VAR residuals and assuming that innovations in the variables placed earlier in the VAR have greater effects on the following variables. Thus, one approach is to order the variables according to the order in which they influence the other variables.

We place macroeconomic variables in the beginning of the VAR ordering since while financial markets respond to monetary policy, the latter is relatively exogenous to the financial system. There are precedents for putting monetary policy instruments before financial variables in the VAR ordering (Thorbecke, 1997, and Chordia, Sarkar and Subrahmanyam, 2005). The ordering of macroeconomic variables (INFL, FED) is based on conventional practice in the macroeconomic literature. They are followed by the business cycle variables, TERM and DEF. Relying on prior evidence (Chordia, Sarkar and Subrahmanyam, 2005), we order the rest of variables as follows: Volat, RET1, RET5, RET10, Bond-Short, Bond-Medium and Bond-Long. The conclusions about IRFs are insensitive to the ordering of market variables.

III.C VAR Innovations: Correlation Matrix

Before proceeding to impulse response analyses, it is of interest to examine contemporaneous relations between innovations in the variables. Accordingly, Table 4, Panels A and B, reports the contemporaneous correlation matrix of the VAR innovations for on-the-run and off-the-run illiquidity, respectively. Again, we focus only on the correlations involving the liquidity variables. Correlations in innovations of illiquidity across maturities are positive, but significant only for off-the-run illiquidity. Shocks to TERM are negatively correlated with innovations in illiquidity. Thus, an increase in the term spread, which is commonly attributed to a monetary policy expansion (e.g., Patelis, 1997), is accompanied by an improvement in bond market liquidity. Shocks to volatility are generally positively correlated with innovations in illiquidity, with the exception of the on-the-run bond-medium illiquidity which has an anomalous negative correlation. Innovations in FED are positively correlated with illiquidity of on-the-run and off-the-run issues. Monetary policy tightening is associated contemporaneously with an increase in bond spreads.

We find that shocks to off-the-run short-term illiquidity are negatively correlated with the returns across all maturities. This is consistent with the results of Amihud (2002) for the stock market: positive shocks to spreads are accompanied by a contemporaneous decrease in prices. This also suggests a special role of the off-the-run short-term bond illiquidity in affecting bond prices across all maturities. We now shed more light on these economic relations by examining impulse response functions.

III.D Impulse Response Functions: Illiquidity

Figure 3, Panel A illustrates the response of short-bond off-the-run illiquidity to a unit standard deviation change in a particular variable, traced forward over a period of 24 months. In the figures, month 0 gives the contemporaneous impact and months 1-24 plot the effect from +1 to +24 months. Bootstrap 95% confidence bands are provided to gauge the statistical significance of the responses. The figure indicates that short-bond illiquidity increases in response to inflation shocks as well as well as monetary tightening associated with a positive shock to FED. This suggests that an increase in inventory-holding and order processing costs due to inflation is reflected in higher transaction costs. TERM and DEF do not have an immediate impact on short-term bond illiquidity.

An innovation in short- and medium-term bond returns results in a reduction in bond illiquidity, while a shock to volatility predicts an increase in short-term illiquidity. These results are consistent with those for the stock market of Chordia, Roll, and Subrahmanyam (2001) who show that up-market moves have a positive effect on liquidity, and with models of microstructure which argue that increased volatility, by increasing inventory risk, tends to increase market illiquidity. Short-bond illiquidity increases contemporaneously in response to its own shock, with the response decaying rapidly from month to month. The effect of illiquidity of other maturities on short-bond illiquidity is insignificant.

Panels B and C present the impulse response functions for medium- and long-bond illiquidity, respectively. Similarly to short-bond illiquidity, a shock to inflation increases long-bond illiquidity (Panel C). However, inflation shocks have no significant impact on medium-bond illiquidity (Panel B). As for short-bond illiquidity, a shock to FED increases medium- and long-bond illiquidity. Thus, monetary policy tightening appears to have an effect across illiquidity of all maturities. TERM and DEF have no significant impact on illiquidity. While innovations in returns have no significant effect on medium-bond illiquidity, innovations to short- and medium-term bond returns decrease long-bond illiquidity. Volatility increases bond illiquidity across all maturities with a very short-lived effect for long-bond illiquidity. Across illiquidity series, while medium-bond illiquidity is only exposed to its own shock, long-bond illiquidity increases in response to its own positive shock as well as to the shocks in short- and medium-bond illiquidity. Shocks to illiquidity to short- and medium- end are transferred into the illiquidity of long end and but the reverse is not true.

The results for on-the-run illiquidity can be summarized as follows.[15] Inflation, TERM and DEF have no significant impact on on-the-run illiquidity. In contrast to off-the-run illiquidity, a shock to FED increases illiquidity of short-term bonds only. Bond returns have no immediate significant impact on illiquidity, while shock to volatility increases illiquidity across all maturities. Thus even though in the Granger-causality results, volatility Granger-causes only the on-the—run illiquidity, in the more complete impulse response analyses, we obtain the result that volatility forecasts illiquidity across all maturities for both on- and off-the-run bonds.

Overall, we conclude that the dynamics of on-the-run illiquidity seem to be driven by a relatively narrow set of economic variables compared to off-the-run illiquidity. While inflation, FED, bond returns and volatility are significant determinants of off-the-run illiquidity, on-the-run illiquidity seems to be affected mainly by volatility. The results are consistent with the notion put forth in Section I that macroeconomic variables affect inventory costs and hence, illiquidity. Apparently, however, active trading in the on-the-

[15] We do not report these results for brevity. They are available upon request.

run bonds shields market makers from increases in inventory costs due to inflation and tighter monetary policy.

III.E Impulse Response Functions: Returns

Figure 4 presents impulse response functions of bond returns in the VAR system with off-the-run bond illiquidity. Focusing on return forecastability from liquidity, we find that the illiquidity of off-the-run short-term bonds is useful in forecasting medium and long-term bond returns. This effect is positive and significant for the first lag for medium-bond return and for two lags for long-bond return.[16][17] Thus, the contemporaneous effect of short-bond off-the-run illiquidity on medium and long-term bond returns is negative and significant (Table 4, Panel B) and the lag effect is positive and especially persistent for long-bond returns. As Amihud (2002) indicates, while higher expected market illiquidity makes investors demand higher expected return and causes ex ante returns to rise, prices should fall contemporaneously with an unexpected rise in illiquidity. However, the lag effect of liquidity on returns should be positive. Our analysis indicates that the effect of illiquidity on bond returns is more pronounced in the more illiquid longer-term bonds.

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[16] Since our data spans thirty years, a natural concern is whether our results hold in the more recent past. To address this, we use a structural break test on the short-term off-the-run illiquidity series (the main variable of interest) to identify a break, which is shown to occur in September 1974. The central results that (i) short-term off the run illiquidity responds more strongly to macroeconomic variables than other liquidities, and (ii) that same illiquidity series predicts the returns of medium and long-term bonds, continue to hold for the more recent subperiod as well.

[17] As indicated in Footnote 10, in October 1996, CRSP switched its data source from the Federal Reserve Bank (FRB) to GovPX indicative quotes. To address the issue that the latter quotes are not necessarily firm ones, we append the FRB illiquidity series with illiquidity obtained from intra-day GovPX data as time-weighted average of valid quoted relative spreads (as opposed to indicative quotes from GovPX). In this procedure, while detrending the illiquidity levels we also use a dummy variable for the post-September 1996 period. The main results continue to hold in this robustness check; details are available from the authors.

From the standpoint of economic significance, we find that a one standard deviation shock to the illiquidity of the off-the run short-term bonds has an annualized impact of 80 basis points on returns of the medium term bonds, and 124 basis points on returns of the long-term bonds. These are economically significant magnitudes.

The other impulse responses indicate that returns are more strongly affected by macro variables at the short-end of the term structure spectrum. Thus, active trading in short-term bonds may cause this market to be more responsive to macro innovations. In addition, returns are affected by volatility innovations for all maturities which is consistent with the traditional risk-return argument.

In unreported results we find that on-the-run illiquidity has no effect on bond returns. Our findings therefore draw attention to the illiquidity of off-the-run short-term bonds: bond returns contain an liquidity premium emanating from off-the-run short-term issues. This can be explained as follows. Our findings demonstrate that illiquidity shocks are transferred from the short end to the long end of the term structure. Specifically, short-term off-the-run illiquidity absorbs market and macroeconomic shocks first and then transmits them into the illiquidity of long-term bonds. Thus, as proposed in Section I, an increase in short-term illiquidity, by portending an increase in illiquidity at other maturities, raises the required return on longer-term bonds. Overall, our results indicate that the liquidity premium in the Treasury bond market found by Amihud and Mendelson (1991) is largely driven by short-term off-the-run illiquidity.

IV. Conclusion

U.S. Treasury markets are critical for asset allocational purposes, and also provide indicators for benchmark riskless rates in the economy. Since bond liquidity influences the efficacy of asset allocation, and aids interest rate discovery, it is important to understand the dynamics of bond market trading costs. Using extensive time-series that span over thirty-five years, we analyze Treasury market illiquidity across maturities and seasonedness. Our aims are to explore whether illiquidities across these attributes are differentially affected by macroeconomic conditions, and to understand variations in the illiquidity premium across bonds.

We find that illiquidity increases in recessions across all maturities. However, the increase is especially pronounced for short-term bonds. The difference between spreads of long- and short-term bonds also increases during recessions for both on-the-run and off-the-run issues. The evidence suggests that investors may shift into short-term bonds during recessions and invest in both on-the-run and off-the-run bonds.

Our results are consistent with the notion that the effect of macro variables on dealer costs are most relevant in the less liquid off-the-run sector. On-the-run illiquidity across all maturities is materially affected only by volatility. However, off-the-run illiquidity is driven by inflation, monetary policy surprises, bond returns and volatility. Overall, off-the-run illiquidity is affected by a larger set of economic variables.

Our Granger causality results indicate that shocks are transferred from the illiquidity of the short end to the illiquidity of the long end of term structure. Specifically, short-term illiquidity Granger-causes illiquidity of other maturities while the reverse is not true. We also explore pricing implications of on-the-run and off-the-run illiquidity of different maturities. We find that off-the-run short-term illiquidity forecasts returns across all maturities, but that the return forecasting ability of either on-the-run illiquidity, or illiquidity at other maturities, is limited. Similar to the effect of stock illiquidity on stock returns (Amihud, 2002), short-term off-the-run illiquidity has a negative contemporaneous impact on bond returns and a positive lag effect. The lag effect persists longer for more illiquid bonds. Our results suggest that short-term off-the-run illiquidity is the primary source of return forecastability (and thus, the liquidity premium) in the Treasury market.

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Table 1. Descriptive Statistics

Bond illiquidity is computed from daily quoted spreads available at CRSP daily Treasury files. *Bond-short* is illiquidity of T-bills, *Bond-medium* is illiquidity of 2 to 5 year bonds, *Bond-long* is illiquidity of 10 year notes. Most recently issued securities are considered as *on-the-run* and the older issues are *off-the-run*. Recessions are determined by NBER business cycle dates. The sample is from November 1967 to December 2005 (458 months).

Panel A. The whole sample

	On-the-run			*Off-the-run*		
	Bond-short	Bond-medium	Bond-long	Bond-short	Bond-medium	Bond-long
Average	0.032	0.106	0.111	0.025	0.108	0.156
St. dev	0.026	0.147	0.076	0.023	0.062	0.105
Median	0.019	0.07	0.099	0.012	0.11	0.142

All numbers are multiplied by 100

Panel B. Recessions (NBER)

	On-the-run			*Off-the-run*		
	Bond-short	Bond-medium	Bond-long	Bond-short	Bond-medium	Bond-long
Average	0.057	0.124	0.147	0.049	0.149	0.234
St. dev	0.03	0.102	0.082	0.029	0.061	0.105
Median	0.066	0.121	0.131	0.054	0.172	0.263

All numbers are multiplied by 100

Panel C. No recessions (NBER)

	On-the-run			*Off-the-run*		
	Bond-short	Bond-medium	Bond-long	Bond-short	Bond-medium	Bond-long
Average	0.027	0.102	0.105	0.02	0.101	0.141
St. dev	0.022	0.153	0.073	0.019	0.059	0.099
Median	0.016	0.063	0.093	0.01	0.079	0.108

All numbers are multiplied by 100

Table 2. Spread (Spread difference between long- and short-term bonds).

The table presents the average spread difference between bonds of long maturity and short-term bonds. Quoted spreads are from CRSP daily Treasury files. *Bond-short* is illiquidity of T-bills, *Bond-long* is illiquidity of 10 year notes. Most recently issued securities are considered as *on-the-run* and the older issues are *off-the-run*. Recessions are determined by NBER business cycle dates. The sample is from November 1967 to December 2005 (458 months).

	On-the-run			***Off-the-run***		
	Bond-long – Bond-short			Bond-long – Bond-short		
	Whole sample	Recession	No recession	Whole sample	Recession	No recession
Diff.	0.08	0.09	0.078	0.131	0.185	0.121
p-value	0.00	0.00	0.00	0.00	0.00	0.00

Diff is multiplied by 100

Table 3. Granger Causality Tests.

The table presents chi-square statistics and p-values (row (2)) of pair-wise Granger Causality tests between endogenous VAR variables. The null hypothesis is that the row variable does not Granger-cause the column variable. Bond illiquidity estimates are based on quoted spreads across bonds of three types of maturities: short (with maturity less than or equal to 1 year), medium (with maturity between 2 and 5 years) and long (with 10 years to maturity). RET1 is the return on 3 month T-bill, RET5 is return on 5-year notes, and RET10 is return on 10 year notes. Bond returns are from CRSP Fixed Term indices file. VOLAT is volatility of returns on 10 year note computed as standard deviation of daily returns over each month. DEF is the default premium, measured as the difference between yields on long-term BAA-rated and AAA-rated bonds. TERM is the term premium, defined as the difference between yields on a 10-year T-note and three-month T-bill. FED is the federal funds rate (indicator of the monetary policy stance). INFL is inflation. The sample is from November 1967 to December 2005 (458 months).

Panel A.

	On-the-run			***Off-the-run***		
	Bond-short	Bond-medium	Bond-long	Bond-short	Bond-medium	Bond-long
Bond-short		**11.34** **(0.001)**	**5.28** **(0.022)**		**11.97** **(0.001)**	**8.46** **(0.004)**
Bond-medium	**4.19** **(0.041)**		0.01 (0.912)	0.07 (0.791)		0.00 (0.960)
Bond-long	0.86 (0.355)	0.05 (0.820)		0.53 (0.467)	**6.44** **(0.011)**	

Panel B.

	On-the-run illiquidity						
	Bond-short	Bond-medium	Bond-long	RET1	RET5	RET10	VOLAT
RET1	0.11 (0.738)	1.11 (0.292)	0.40 (0.526)				
RET5	**8.64** **(0.003)**	0.12 (0.73)	0.01 (0.928)				
RET10	**10.43** **(0.001)**	1.54 (0.214)	0.01 (0.905)				
VOLAT	**3.78** **(0.05)**	**50.69** **(0.00)**	**21.92** **(0.00)**				
DEF	0.05 (0.832)	0.08 (0.771)	**9.05** **(0.003)**				
TERM	**5.31** **(0.021)**	0.36 (0.549)	0.2 (0.6587)				
FED	**5.88** **(0.015)**	0.01 (0.916)	**2.9** **(0.089)**				
INFL	**5.15** **(0.023)**	1.74 (0.188)	0.33 (0.563)				
Bond-short				**10.25** **(0.001)**	1.17 (0.279)	0.97 (0.325)	**7.68** **(0.006)**
Bond-medium				0.63 (0.426)	0.16 (0.689)	2.09 (0.148)	**7.43** **(0.006)**
Bond-long				0.06 (0.812)	0.39 (0.533)	0.00 (0.963)	0.12 (0.725)

Panel C.

	Off-the-run illiquidity						
RET1	0.73 (0.392)	5.79 (0.016)	1.81 (0.178)				
RET5	**28.80** **(0.00)**	0.12 (0.728)	**11.29** **(0.001)**				
RET10	**20.84** **(0.00)**	1.24 (0.265)	**6.21** **(0.013)**				
VOLAT	0.19 (0.661)	9.63 (0.002)	1.04 (0.309)				
DEF	**8.62** **(0.003)**	1.7 (0.193)	0.41 (0.522)				
TERM	**7.13** **(0.008)**	**5.63** **(0.018)**	1.76 (0.185)				
FED	**28.61** **(0.00)**	**5.53** **(0.019)**	1.04 (0.307)				
INFL	**7.95** **(0.005)**	0.72 (0.398)	**8.7** **(0.003)**				
Bond-short				**11.57** **(0.001)**	**2.87** **(0.091)**	1.76 (0.185)	**6.36** **(0.012)**
Bond-medium				**2.82** **(0.093)**	0.01 (0.907)	0.3 (0.583)	**19.36** **(0.00)**
Bond-long				**9.29** **(0.002)**	1.3 (0.254)	0.38 (0.539)	**7.1** **(0.008)**

Table 4. Contemporaneous correlation between VAR innovations.

The table presents results from a VAR with endogenous variables INFL, FED, TERM, DEF, Volat, RET1, RET5, RET10, Bond-Short, Bond-Medium and Bond-Long. It is estimated with one lag and a constant term. Bond illiquidity estimates are based on quoted spreads across bonds of three types of maturities: short (with maturity less than or equal to 1 year), medium (with maturity between 2 and 5 years) and long (with 10 years to maturity). RET1 is the return on 3 month T-bill, RET5 is return on 5-year notes, and RET10 is return on 10 year note. Bond returns are from CRSP Fixed Term indices file. VOLAT is volatility of returns on 10 year note computed as standard deviation of daily returns over each month. DEF is the default premium, measured as the difference between yields on long-term BAA-rated and AAA-rated bonds. TERM is the term premium, defined as the difference between yields on a 10-year T-note and three-month T-bill. FED is the federal funds rate (indicator of the monetary policy stance). INFL is inflation. The sample is from November 1967 to December 2005 (458 months). Numbers in bold denote significance at 5% level.

Panel A. On-the-run illiquidity

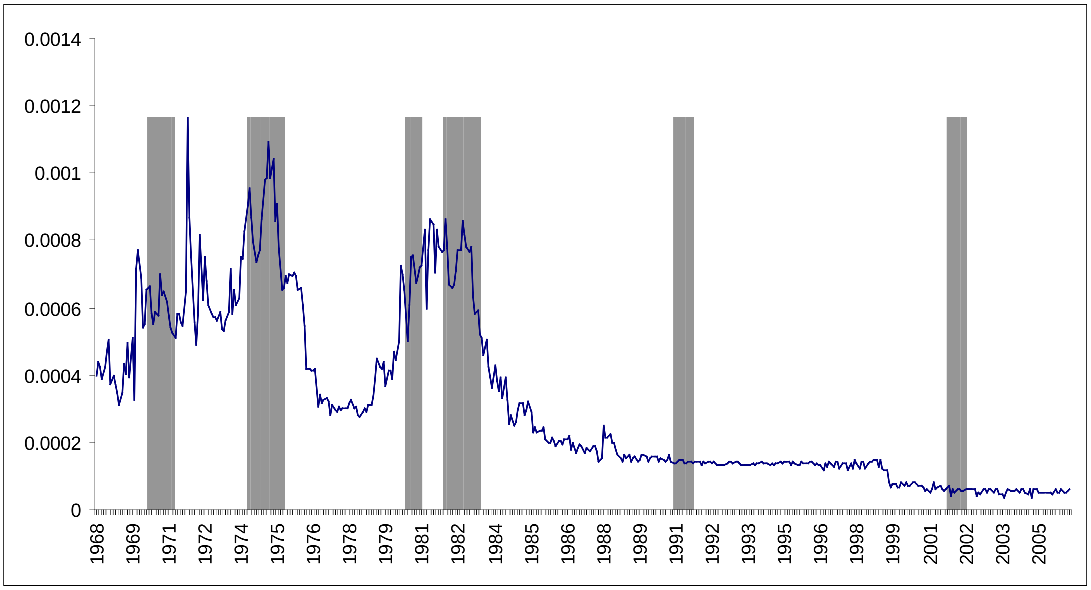
	INFL	FED	TERM	DEF	Volat	RET1	RET5	RET10	Bond-short	Bond-Medium	Bond-Long
Bond-short	0.04	**0.16**	**-0.14**	-0.05	0.08	-0.09	**-0.10**	-0.07	1.00		
Bond-medium	0.01	**0.10**	**-0.13**	-0.09	**-0.17**	0.02	0.01	0.06	-0.01	1.00	
Bond-long	0.02	0.03	**-0.13**	-0.02	**0.10**	0.03	0.05	0.09	0.06	0.06	1.00

Panel B. Off-the-run illiquidity

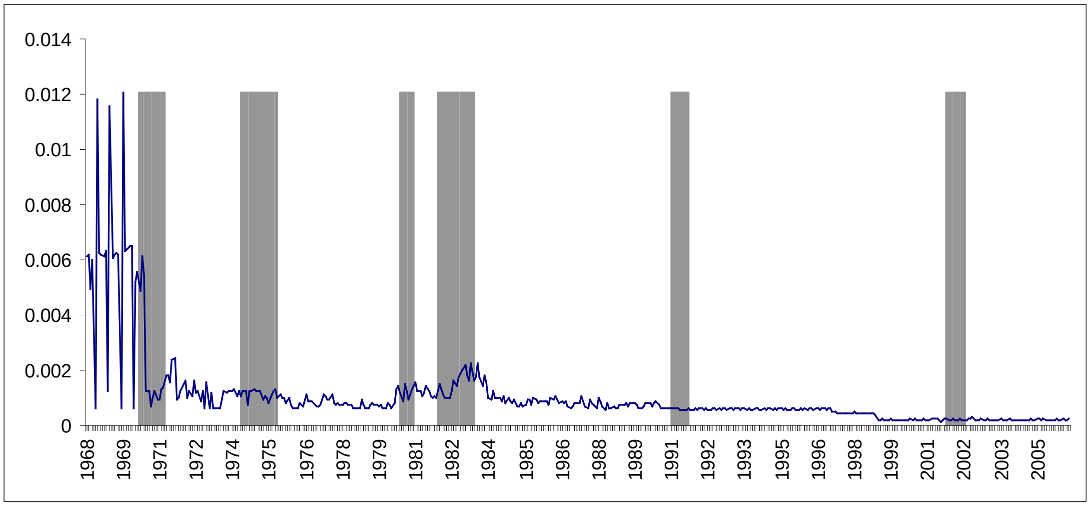
	INFL	FED	TERM	DEF	Volat	RET1	RET5	RET10	Bond-short	Bond-Medium	Bond-Long
Bond-short	0.08	**0.27**	**-0.24**	-0.01	**0.17**	**-0.16**	**-0.18**	**-0.11**	1.00		
Bond-medium	0.02	0.01	-0.06	-0.07	0.02	0.01	0.02	0.07	-0.03	1.00	
Bond-long	**0.11**	**0.25**	**-0.24**	-0.04	0.08	0.00	**-0.14**	-0.05	**0.27**	**0.26**	1.00

Figure 1.

Panel A. Illiquidity of on-the-run short-term bonds



Panel B. Illiquidity of on-the-run medium-term bonds



Panel C. Illiquidity of on-the-run long-term bonds

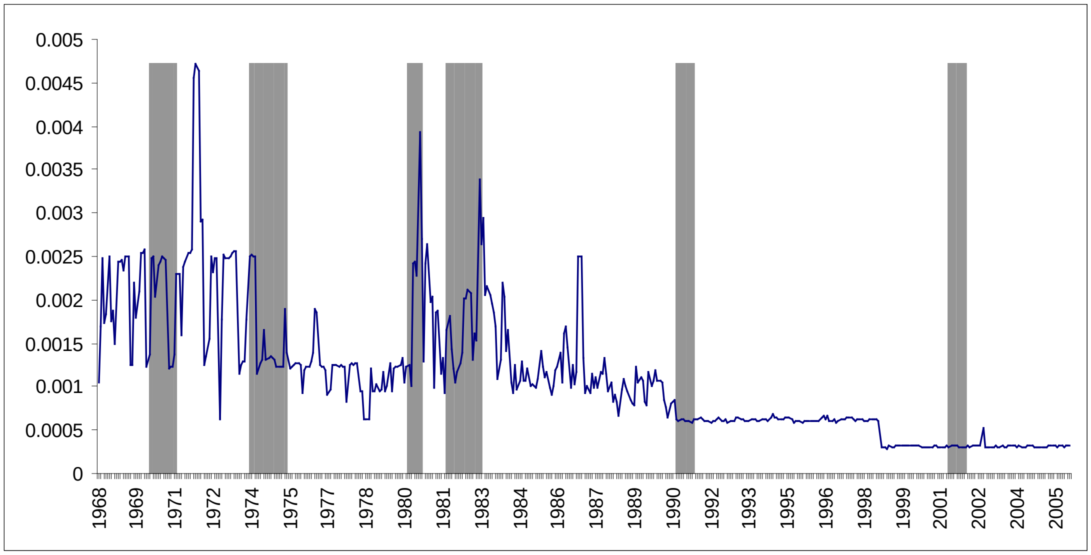
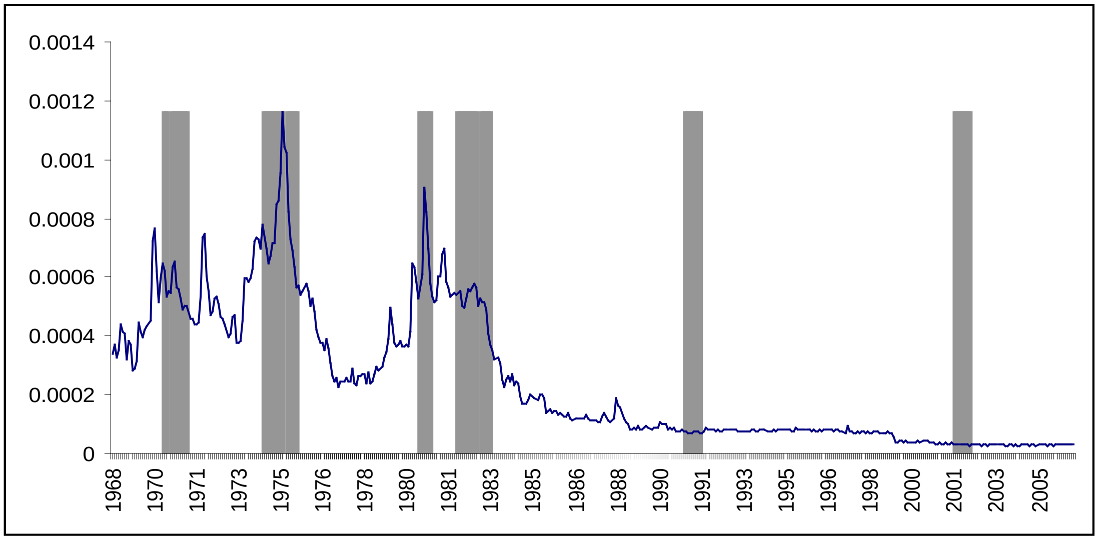
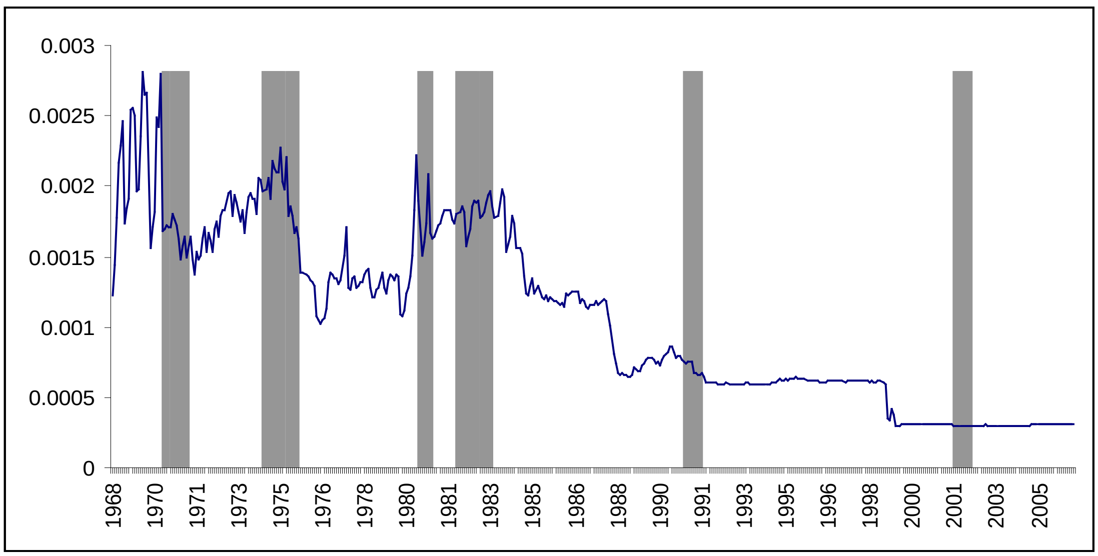


Figure 2.

Panel A. Illiquidity of off-the-run short-term bonds



Panel B. Illiquidity of off-the-run medium-term bonds



Panel C. Illiquidity of off-the-run long-term bonds

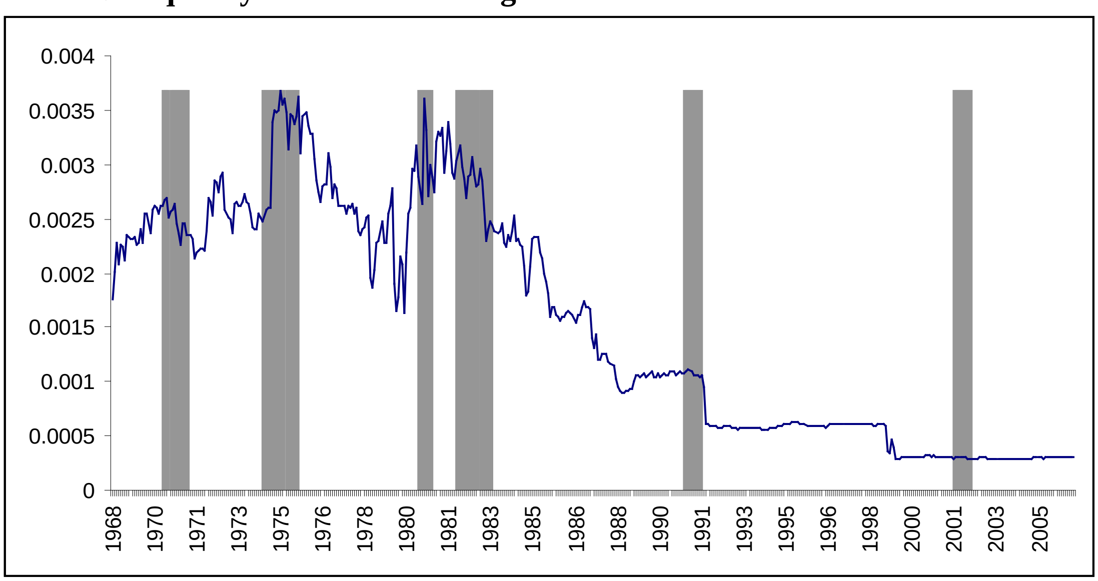
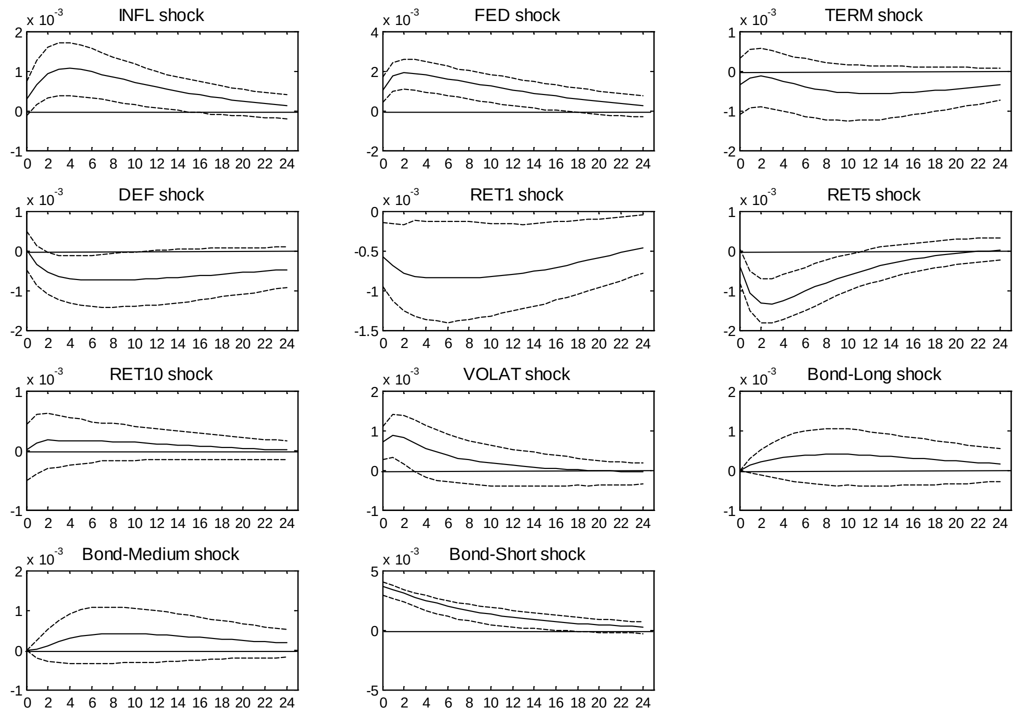


Figure 3. Off-the-Run Illiquidity

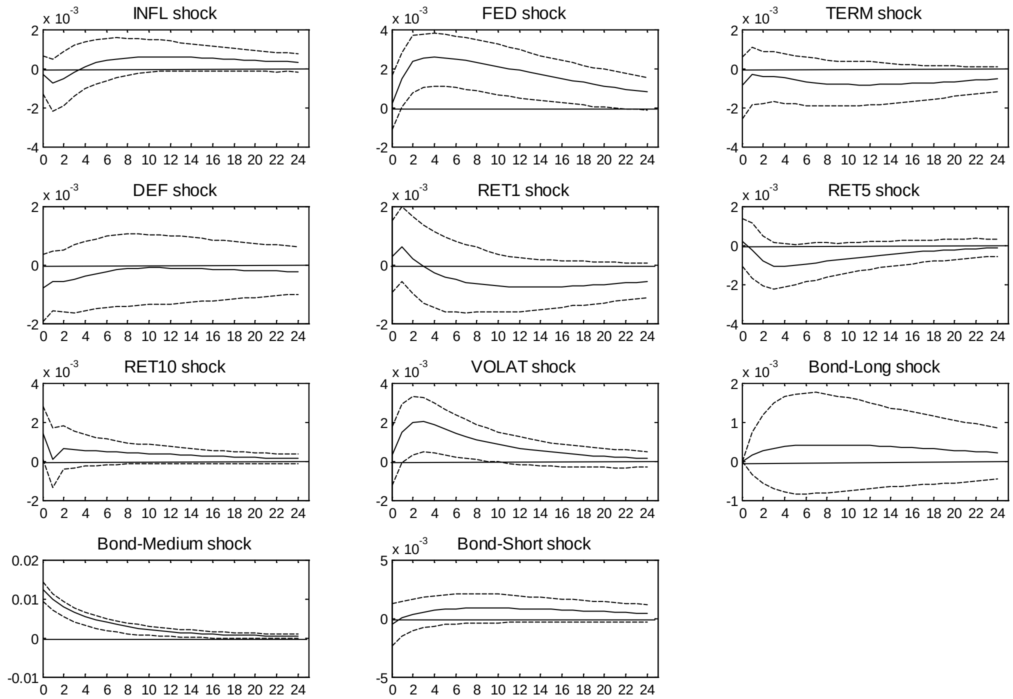
Panel A. Response of Short-Bond Illiquidity to Endogenous Variables.

Response to Cholesky one standard deviation. Dashed lines represent bootstrap 95% confidence bands derived via 1,000 bootstrap simulations



Panel B. Response of Medium-Bond Illiquidity to Endogenous Variables.

Response to Cholesky one standard deviation. Dashed lines represent bootstrap 95% confidence bands derived via 1,000 bootstrap simulations



Panel C. Response of Long-Bond Illiquidity to Endogenous Variables.

Response to Cholesky one standard deviation. Dashed lines represent bootstrap 95% confidence bands derived via 1,000 bootstrap simulations

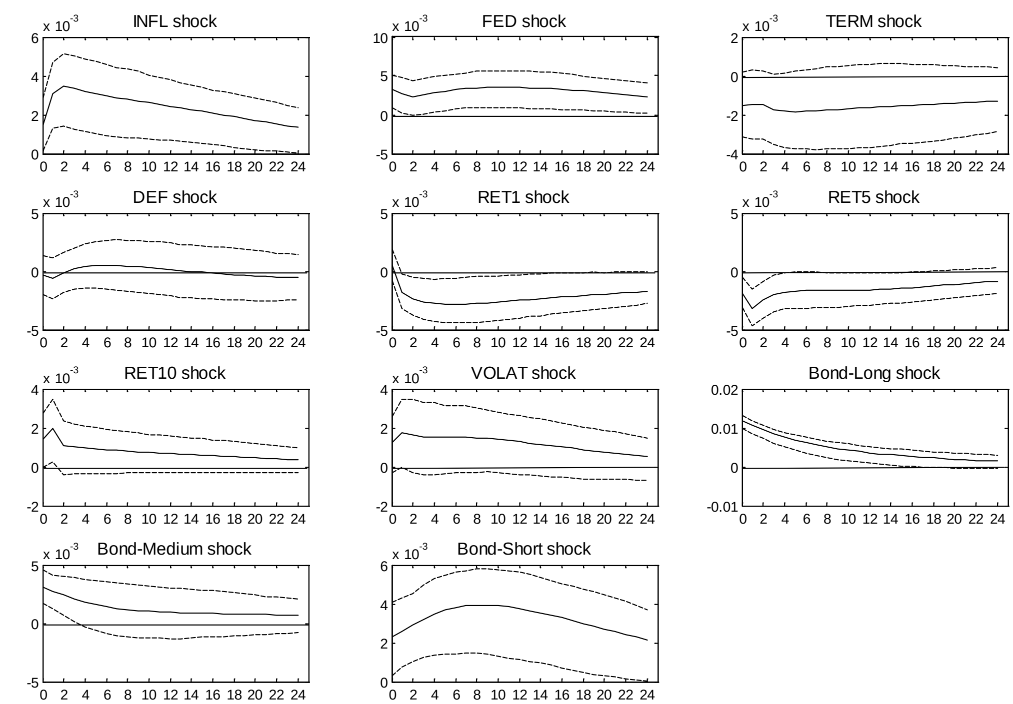
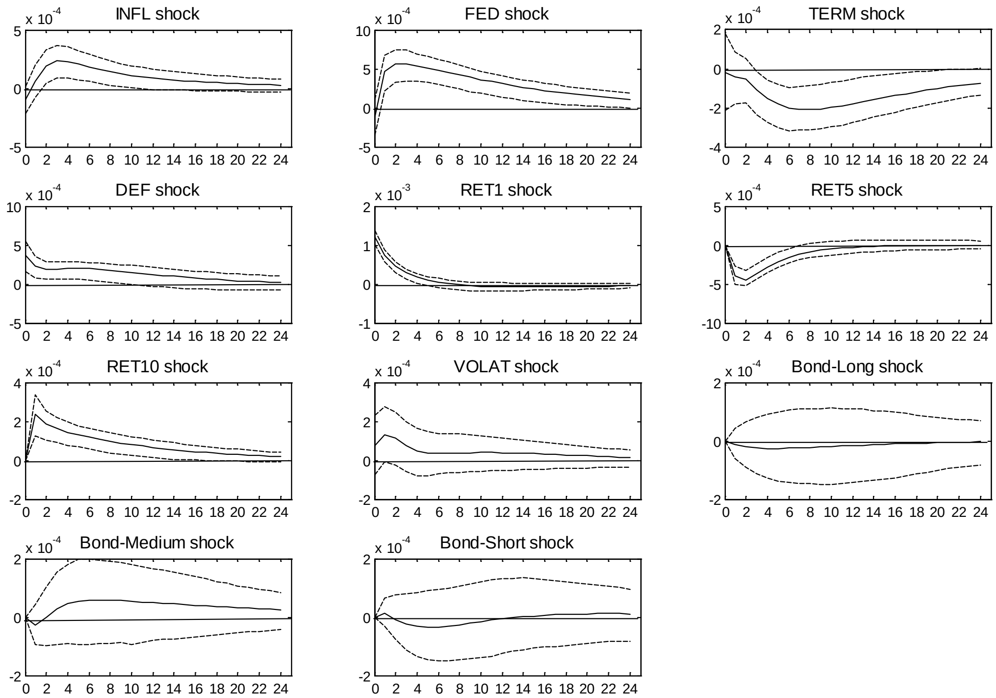


Figure 4. Returns and Off-the-Run Illiquidity

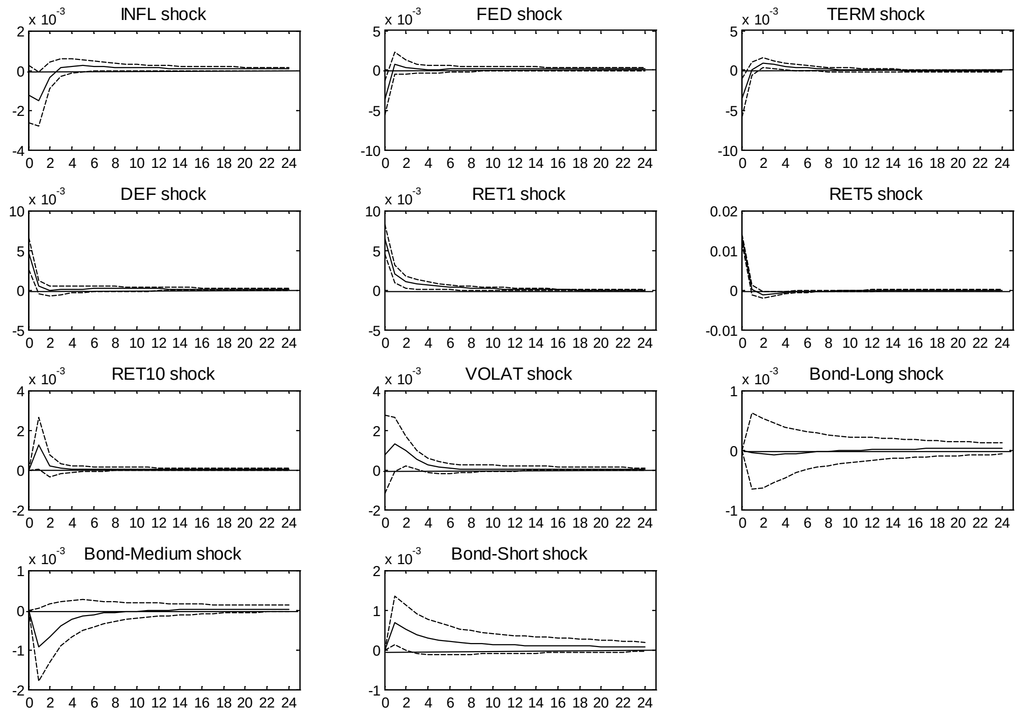
Panel A. Response of Short-Bond Return (RET1) to Endogenous Variables.

Response to Cholesky one standard deviation. Dashed lines represent bootstrap 95% confidence bands derived via 1,000 bootstrap simulations



Panel B. Response of Medium-Bond Return (RET5) to Endogenous Variables.

Response to Cholesky one standard deviation. Dashed lines represent bootstrap 95% confidence bands derived via 1,000 bootstrap simulations



Panel C. Response of Long-Bond Return (RET10) to Endogenous Variables.

Response to Cholesky one standard deviation. Dashed lines represent bootstrap 95% confidence bands derived via 1,000 bootstrap simulations