Private Information Flow and Price Discovery in the U.S. Treasury Market

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Abstract

Existing studies find that U.S. Treasury bond price changes are related to public information shocks, as manifested in macroeconomic news announcements and events. The literature also shows that heterogeneous private information contributes significantly to price discovery for U.S. Treasury securities. In this paper, we use high frequency transaction data for 2-, 5-, and 10-year Treasury notes and employ a Markov switching model to identify intraday private information flow in the U.S. Treasury market. We show that the probability of private information flow (PPIF) identified in our model effectively captures non-transitory price effects on U.S. Treasury securities. In addition, our results imply that public information shocks and heterogeneous private information are the main factors of bond price discovery on announcement days, whereas private information and liquidity shocks play more important roles in bond price variation on non-announcement days. Most interestingly, our results highlights that the role of heterogeneous private information is more prominent when public information shocks are either relatively high or relatively low. Furthermore, heterogeneous private information flow is followed by low trading volume and low market depth. The pattern is more pronounced on non-announcement days.

Key Words: Private Information Flow, Price Discovery, Order Flow Impact, Market Liquidity.

I. Introduction

Asset prices are subject to information shocks in financial markets and investors constantly update their valuation of assets as a result of new information arrival. Existing studies on the U.S. Treasury market show that bond price changes are related to public information shocks, as manifested in macroeconomic news announcements and events. Some notable studies include Fleming and Remolona (1999) and Balduzzi, Elton and Green (2001), which find that public information shocks measured by announcement surprise have a significant effect on the price of U.S. treasury instruments. In addition, Fleming and Remolona (1997) find that the 25 largest price changes of the on-the-run 5-year note are all associated with news announcements. Similar findings are documented in Bollerslev, Cai, and Song (2000) over a later sample period.

Recent literature further documents that private information flow also contributes significantly to price discovery in the U.S. Treasury market. Green (2004) finds that post-announcement order flow has a higher information content in the 5-year Treasury note relative to non-announcement days. Pasquariello and Vega (2007) find that private information manifests on days with larger belief dispersion. Menkveld, Sarkar and van der Wel (2008) provide similar findings for 30-year Treasury bond futures. Brandt and Kavajecz (2004) find that order flow imbalances account for up to 26% of the day-to-day variation in yields on days without major macroeconomic announcements. All studies point out that order flow affects the price discovery process in the Treasury market because order flow aggregates heterogeneous private information.

The focus of this paper is to extend existing studies and examine intraday private information flow in the U.S. Treasury market on both announcement and non-announcement days. We argue that analysis of information arrival at a high frequency is important and crucial in the U.S. Treasury market. This is because information disseminates quickly into bond prices. For instance, Green (2004) points out that private information dissipates within the first fifteen minutes after announcements. In addition, the Treasury market offers an ideal setting to disentangle public information flow versus private information flow. The interpretation of private information in our study is similar to that in Brandt and Kavajecz (2004). That is, it can take two different forms. One form of private information stems from heterogeneous interpretation of public information. In particular, some investors may have superior ability in interpreting public information due to experience or, for example, the use of more sophisticated models (Brandt and Kavajecz (2004)). The other form refers to certain investors' access to exclusive sources of information. An example of such private information is that dealers may have private access to client order flow and thus gain information exclusive to other investors. As shown in Evans (2002) and Evans and Lyons (2002) using data in foreign exchange market, such information has predictive power of short-term price movements. Focusing on announcement days, we examine how heterogeneous private information among investors interacts with public information flow in driving bond price discovery. Focusing on non-announcement days, we examine how private information exclusive to certain group of investors drives the price discovery process of U.S. Treasury securities. In both cases, heterogeneous private expectations are aggregated through trading into market price in an environment with imperfect information. Finally, the Treasury market provides a clean setting to examine heterogenous private information across market participants. With no cash flow risk, different valuation of Treasury securities across market participants is primarily in the absence of heterogeneous expectations.

One challenge of our study is that unlike public information flow in the Treasury market, which generally coincides with news announcements, private information flow is not directly observed. In this paper, we follow the literature and use the impact of order flow on bond prices to infer private information flow. For example, Brandt and Kavajecz (2004) argue that order flow impact effectively captures heterogeneous information flow in the U.S. Treasury market. Empirically, Green (2004), Pasquariello and Vega (2007) use order flow impact to proxy for the level of information asymmetry on announcement versus non-announcement days in the Treasury market. Loke and Onayev (2007) also find order flow is state-varying in the S&P 500 futures market. Using information from order flow impact, we specify a Markov switching model to identify private information flow. Using high frequency transaction data of the 2-, 5-, and 10-year Treasury notes, we obtain 5-minute estimates of the probability of private information flow (PPIF hereafter). In this respect, our model can be viewed as an extension of the existing PIN model by Easley et al. (2002) and Li et al. (2009).

The data used in our study is obtained from the BrokerTec electronic limit order book platform on which secondary interdealer trading occurs. It contains not only tick-by-tick information on transaction and market quotes but also information of the entire limit order book of the on-the-run 2-year, 5-year, and 10-year notes. This allows us to examine the effect of heterogeneous private information in high frequency. The detailed information on the limit order book also allows us to examine how liquidity dynamics interact with private information. A novel aspect of our paper is that we examine how liquidity reacts to information uncertainty. Given that the timing and the nature of private information are uncertain on non-announcement days, we examine how trading activities and placement of limit orders differ from that on announcement days. Data on announcements comes from Bloomberg and includes date, time and values for expected and actual announcements. Since surveys of market participants provide ex ante expectations of major economic announcements, measures of announcement surprises or unexpected public information shocks can be constructed.

Our results show that PPIF is higher for longer maturity bonds, and higher on announcement days than on non-announcement days. Consistent with Brandt and Kavajecz (2004), our finding suggests that price discovery manifests in less liquid markets. In addition, on announcement days, PPIF peaks at the time of an announcement and immediately after announcement. This is consistent with Green's (2004) finding that the role of private information is higher at and immediately after announcements.

One of the key questions is whether the PPIF identified from the Markov switching model indeed captures information effect on bond prices. To answer this question, we follow the literature to use permanent price impact as a yardstick to measure the information content of PPIF. The main premise of our analysis is that if PPIF captures private information flow then we should expect bond price changes associated with high PPIF to have non-transitory price impact whereas bond price changes associated with low PPIF to have only transitory effects. We employ the nonparametric test in Kaniel and Liu (2006) and a probit model to test the hypothesis. In the probit model, we explicitly control for the effect of public information shocks as measured by announcement surprises. The results of both the nonparametric test and the probit model show that bond price changes associated with high PPIF in fact exhibit significant permanent price impact over 30 minutes, 1-hour and 1-day horizons on both announcement and non-announcement days. Although the impact of PPIF drops overtime, it remains significant up to 1-day interval. In particular, the results on non-announcement days provide evidence that the information content captured by PPIF is largely private in nature.

We then examine how much explanatory power PPIF has for price bond variation by regressing bond price volatility on PPIF and other control variables. For non-announcement days, the regression uses 15-minute realized volatility over the entire day, whereas for announcement days the regressions are performed over two 15-minute intervals after announcement time. For both announcement and non-announcement days, we include liquidity shocks in the regression, whereas for announcement days we also include major announcement surprises to control for the effect of public information shocks. Consistent with existing studies, our results show that bond price variation is positively related to public information shocks. Liquidity shocks have a more significant effect on price variation on non-announcement days. Most importantly, for both announcement and non-announcement days, PPIF has significant explanatory power for bond variance, even after controlling for public information shocks and liquidity shocks. The sensitivity of bond price variation with respect to PPIF increases with maturity. This is consistent with the notion that heterogeneous private information plays a more important role in less liquid markets. Comparing announcement days with non-announcement days, PPIF actually plays a more important role on announcement days, especially immediately after announcement. Though the role of private information drops in the second 15-minute interval, PPIF still significantly affects bond price variations. Thus, the information content of public news announcements is not impounded into bond prices instantaneously. Instead, it takes trading among investors to discover new equilibrium price.

To further examine how heterogeneous private information interacts with public information shocks in driving the price discovery process on announcement days, we sort all announcements into terciles according to the magnitude of public information shocks (i.e. absolute standardized announcement surprises). In each tercile, we calculate the average PPIF during the post-announcement period. Interestingly, we observe a rather consistent U-shaped pattern in PPIF. That is, for announcements with relatively large or relatively small public information shocks, there is a higher level of private information flow in the market. On the other hand, when announcement surprise is at a medium level, the size of private information flow is low. Our conjecture is that when announcement surprise is at a medium level, there is less disagreement or divergent interpretation of the announcement among investors. When the information shock is large, there is likely more disagreement and diverse interpretation of the announcement among investors. Interestingly, when public information shock is small, heterogeneous private information also plays an important role in driving bond prices. To confirm our conjecture, we also compute realized volatility in the post-announcement period for each of the tercile based on absolute announcement surprises. The return volatility exhibits a similar U-shaped pattern as the PPIF. This is an indication that bond prices converge relatively slower when public information shocks are either high or low.

Finally, we look at how market liquidity is related to private information arrival and how it evolves subsequently. We sort the liquidity measures into terciles according to PPIF and examine how they evolve in the subsequent two-hour interval. The results show that a higher level of private information is associated with lower trading volume, lower market depth and wider bid-ask spread concurrently and in the subsequent two-hour horizon. The results suggest that market participants refrain from trading and posting new limit orders in the presence of private information. However, market liquidity evolves differently after private information arrival on announcement days. Although market remains less liquid after private information arrival on announcement days, spread and market depth in the highest PPIF group on announcement days reverts in the subsequent two-hour horizon. However, spread remains wide and market depth remains low for the next two hours on non-announcement days. Our findings suggest market participants refrain from posting aggressive limit orders for prolonged period when the nature of information arrival is uncertain on non-announcement days.

The rest of paper is structured as follows. Section II describes the data used in our study and the Markov switching model. Section III and IV present main empirical results. Section V concludes.

II. Data and Model

A. Data

The U.S. Treasury securities data is obtained from BrokerTec, an interdealer electronic trading platform in the secondary wholesale U.S. Treasury securities market. Prior to 1999, the majority of interdealer trading of U.S. Treasuries occurred through interdealer brokers. Since 1999, the majority of trading of on-the-run Treasuries has migrated to two electronic platforms, the eSpeed and the BrokerTec. Mizrach and Neely (2008) and Fleming and Mizrach (2008) provide detailed descriptions of the migration to electronic platform and price discovery on the BrokerTec platform. According to Barclay, Hendershott and Kotz (2006), the electronic market shares for the 2-, 5- and 10-year bond are, respectively, 75.2%, 83.5% and 84.5% during the period of January 2001 to November 2002. By the end of 2004, the majority of secondary interdealer trading was through electronic platforms with over 95% of the trading of active issues occurred on electronic platforms.[1]

BrokerTec is more active in the trading of 2-, 5- and 10-year Treasury notes than eSpeed. The BrokerTec platform functions as a limit order book. Traders can submit limit orders, i.e., orders that specify both price and quantity posted on the book, or they can submit marketable limit orders, i.e., orders with a price better than or equal to the best price on the opposite side of the market, to ensure immediate execution. Limit order submitters can post "iceburg" orders, where only part of their orders is visible to the market and the remaining part is hidden. All orders on the book except the hidden part of the orders are observed by market participants. The orders remain in the market until matched, deleted, inactivated, loss of connectivity, or the market closes. The market operates more than 22 hours a day from Monday to Friday. After the market closes at 5:30 p.m. eastern time (EST), it opens again at 7:00 p.m. EST.

The sample period is from January 2004 to June 2007. Days with early closing before public holidays are excluded since liquidity is typically low for these days. The dataset consists of over 700.8 million observations and 16.9 million transactions. The dataset contains the tick-by-tick observations

[1] See "Speech to the Bond Market Association", December 8, 2004 by Michael Spencer, founder and chief executive of ICAP PLC.

of transactions, order submissions, and order cancelations. It includes the time stamp of transactions, quotes, the quantity entered and deleted, the side of the market and, in the case of a transaction, an aggressor indicator. Fleming and Mizrach (2008) provide a more detailed description of the microstructure of BrokerTec platform. We use data from 7:30 a.m. EST to 5:00 p.m. EST since trading is more active during this time interval. This interval also contains all pre-scheduled U.S. news announcements, and it provides us with 9.5 hours of trading and 114 five-minute return observations each day.

Table I provides descriptive statistics of the data. Spreads are defined both in relative terms and in ticks. Relative spread is defined as

$$\text{relative spread} = (\text{best bid price} - \text{best ask price})/\text{mid-quote} \tag{1}$$

and measured at the end of each 5-minute interval and averaged over the trading day. Tick spread is defined similarly. The tick size of the 2-year and 5-year note is 1/128, whereas that of the 10-year note is 1/64. Daily return volatility is calculated as the square-root of the sum of squared log mid-quote difference sampled at 5-minute intervals

$$\text{return volatility} = (\sum_{i=1}^{114} (\ln p_i - \ln p_{i-1})^2)^{1/2} \tag{2}$$

where the mid-quote is defined as $p_i = (\text{best bid price} + \text{best ask price})/2$. The average (hidden) depth (in millions) at the best bid/ask is the total (hidden) observed depth at the best price on both the bid and ask side of the market measured at the end of each 5-minute interval and averaged over the trading day. The average depth and average hidden depth in the entire order book are defined similarly.

BrokerTec is a highly liquid platform over our sample period. As shown in Table I, the relative spread is smallest for the 2-year note with a sample mean of 0.0109%, followed by the 10-year note (0.0118%) and 5-year note (0.0126%). Trading volume is highest for the 2-year note ($25.86 billion per day), followed by the 5-year note ($23.43 billion per day), and 10-year note ($20.70 billion per day). Intraday return volatility generally increases with maturity, possibly due to higher bid-ask spread and less market depth at longer maturities. The 2-year note has the deepest book, both at the best quote ($547.09 million) and the entire book ($4,092 million). Hidden depth is low in general, and hidden orders at the best quote are less than 5% of the observed depth at the best quote for all three maturities.

Figure 1 presents the intra-day activities in the 2-year note. The intraday patterns for other notes are similar and thus not reported for brevity. Consistent with the findings in Fleming (1997), trading volume peaks first in the 8:30 to 10:00 EST interval and goes up again from 13:00 to 14:00 EST. These two intervals overlap with major macroeconomic announcements. Relative spread is higher at the beginning (before 8:30 EST)) and the end of the trading day (after 16:00 EST). The depth at the best price is thinner before 8:30 EST and after 15:00 EST. For the rest of the day, the depth on the book is on average over $600 million. The level of hidden depth is higher at noon and it goes up again after 15:00 EST. This finding suggests that market participants hide more of their orders when there is less total depth in the market.

Data on macroeconomic news announcements and the survey of market participants come from Bloomberg and Briefing.com's economic calendar. Balduzzi, Elton and Green (2001) show that professional forecasts based on surveys are neither biased nor stale. Announcement days are defined as days in which one or more announcement took place. To ensure the list of announcements is comprehensive, we start with the 25 announcements from Pasquariello and Vega (2007). We then include 7 additional economic announcements: FOMC minutes, ISM service, NY Empire State Index, Chicago PMI, Existing Home Sales, Philadelphia Fed Index, and ADP National Employment Report. In addition to pre-scheduled news announcements, we collect the auction result release times for 2-year, 5-year and 10-year notes. Lastly, we collect the release of the testimony of Semiannual Monetary Policy Report and Economic Outlook. The full list of announcements can be found in Table II. Following Balduzzi, Elton and Green (2001) and Andersen, Bollerslev, Diebold and Vega (2007), the standardized announcement surprise is defined as

$$Sur_{jt} = \frac{A_{jt} - E_{jt}}{\hat{\sigma_j}} \tag{3}$$

where A_{jt} is the actual announcement, E_{jt} is the median forecast for news j on day t, and $\hat{\sigma_j}$ is the standard deviation of $A_{jt} - E_{jt}, t = 1, 2, \cdots, T$.

B. The Markov Switching Model

In this section, we present the Markov switching model used to identify private information flow in the Treasury market. Private information arrival is modeled through state-varying order flow impact. Recent literature documented that order flow aggregates heterogeneous private information into the price discovery process and the price impact of order flow measures the extent of private information incorporated into price. Furthermore, there is evidence that the impact of order flow is state-varying. Brandt and Kavajecz (2004) find that the impact of order flow on yields is strongest when liquidity is low. Green (2004) finds that order flow has a greater impact on bond price when the price change at announcement is large. Pasquariello and Vega (2007) find that order flow impact is strongest when dispersion of belief among market participants are high. Loke and Onayev (2007) also find a state-varying level of order flow impact in the S&P 500 futures market.

One common focus of the above studies is the comparison of the impact of order flow in different market conditions, e.g. liquid versus illiquid market, announcement versus non-announcement days, etc. As such, the findings in existing studies are generally aggregated over specific market conditions. This could be the reason that findings documented in different studies sometimes appear to be conflicting with each other. For example, Green (2004) identifies greater informational role of order flow impact when the market is very liquid, while on the other hand, Brandt and Kavajecz (2004) find the opposite.

In this paper, we deal with the latent nature of private information flow using a Markov switching model. Let s_t represents the state of price impact of order flow at time t. The two states of our Markov switching model represent, respectively, a state with low price impact of order flow ($s_t = 1$) and a state with high price impact of order flow ($s_t = 2$). The transition probabilities are defined as

$$Pr(s_t = 1|s_t = 1) = \psi_{11} \tag{4}$$

$$Pr(s_t = 2|s_t = 1) = 1 - \psi_{11} \tag{5}$$

$$Pr(s_t = 1|s_t = 2) = 1 - \psi_{22} \tag{6}$$

$$Pr(s_t = 2|s_t = 2) = \psi_{22} \tag{7}$$

The high price impact of order flow state captures the existence of private information. In the Markov switching model, we also incorporate standardized surprise of important news announcements to control for the effect of public information shocks on the dynamics of return and volatility. More specifically,

$$\Delta p_t = \rho \Delta p_{t-1} + \mu + \mu_{PPIF} * D_t + \beta OF_t + \beta_{PPIF} * OF_t * D_t + \sum_{j=1}^{N} \gamma_j Sur_{jt} + \varepsilon_t \tag{8}$$

where OF_t is order flow measured as the number of bid trades minus the number of ask trades, the latent dummy variable D_t is equal to 1 when the price impact of order flow is high (i.e. $s_t = 2$) and $D_t = 0$ when the price impact of order flow is low (i.e. $s_t = 1$) and the error term, ε_t. The erro term is assumed to be normally distributed with mean zero and variance is a function of the magnitude of public information shock following Andersen et al. (2003), $\varepsilon_t \sim N(0, \sigma + \sum_{j=1}^{N} \theta_j |Sur_{j,t}|)$. In this model, return is affected by both public information shocks and private information arrival and β_{PPIF} captures the extent of private information. If the price impact of order flow is larger when private information arrives as found in Brandt and Kavajecz (2004), Green (2004), Pasquariello and Vega (2007) and and Menkveld et al. (2008), then β_{PPIF} should be significantly positive. Another implication of the model is about how efficiently the market incorporates private information flow. If private information is incorporated quickly into asset prices, then the transitional probability from private information arrival state to private information arrival state, ψ_{22}, should be lower than the transitional probability from no informed trading to no informed trading ψ_{11}. The intuition is that private information dissipates quickly in an efficient market and informed trading is less likely to continue in the next period.

To ensure that our result is not driven by the intraday seasonality as evident in Figure 1, we diurnally adjust returns by

$$\Delta p_t = \frac{\tilde{\Delta p}_{t,j}}{\sigma_j^{adj}} \tag{9}$$

where $\Delta \tilde{p_{t,j}}$ is the raw unadjusted log return (times 1,000) within the jth 30-minute interval within the trading day [2] and σ_j^{adj} is the intraday adjustment factor. We calculate the adjustment for intraday trading effect using only data from non-announcement days. That is, σ_j^{adj} is the average realized volatility

[2]We divide the trading day into thirteen 30-minute intervals.

during the j interval over all non-announcement days divided by the average realized daily volatility over all non-announcement days.

Using estimates of the Markov switching model, we calculate the probability of private information flow (PPIF) implied by the Markov switching model. The conditional probability of private information flow is given by $PPIF_t = (S_t = 2|I_t)$, where I_t is the information set at time t and is calculated using the EM algorithm as described in Hamilton (1990).

III. Empirical Results

A. Estimation Results

We estimate the Markov switching model as defined in (17) using 5-minute data for the 2-, 5- and 10-year treasury notes. Since we have more than 30 pre-scheduled announcements, it is infeasible to include all of them in the estimation of the model. Our choice of announcements is based on findings in previous literature. More specifically, we first include 7 "influential announcements" from Pasquariello and Vega (2007): Change in Nonfarm Payrolls (Nonfarm), Consumer Confidence Index (C.Confi), ISM Index (ISM), Initial Jobless Claims (Ini.Jobls.), Leasing Indicators (Leading), New Home Sales (NewHome) and Retail Sales (Retail). Given these announcements, we add announcements to the model one-by-one sequentially. An announcements is kept in the model if it significantly increases model fit, as measured by the increase in likelihood function. Five additional announcements are included as a result: CPI, Durable Goods (Dur), GDP advance (GDPadv), PPI and FOMC [3].

Table 3 reports the estimation results. The estimates of β_{PPIF} are significantly positive for all three maturities. Another interesting observation is that the estimates of price impact of order flow increases with maturities. This holds for both states with low and high impact of order flow. Given that the depth of both the 5-year and the 10-year notes is one-fifth that of the 2-year note, it is therefore easier for a transaction of a given size to walk up/down the book and create a larger price impact. Thus our findings are consistent with Brandt and Kavajecz (2004) finding that private information manifests in a

[3] As there is no announcement surprise in FOMC during the sample period, we set a dummy variable equal to one if FOMC occurs on a trading day and zero otherwise

less liquid market.

Turning to transitional probabilities, the results show that the transitional probability of remaining in State 2 (ψ_{22}), the high price impact of order flow state, is lower than the transitional probability of remaining in State 1 (ψ_{11}), low price impact of order flow impact for all maturities. The result implies that private information dissipates quickly in an efficient market. Another finding is that ψ_{22} increases in maturity. This means the private information arrival state is more likely to persist in longer maturity notes. The finding is consistent with the fact that price formation or resolution of information uncertainty is slower in the less liquid 5- and 10-year notes markets.

Table 4 reports the summary statistics of PPIF estimates. We find that the sample mean of PPIF increases with maturities in both announcement days and non-announcement days. The finding is consistent with Brandt and Kavajecz (2004) that price discovery manifest in less liquid markets. The sample mean of PPIF is higher on announcement days than on non-announcement days. The finding is consistent with existing empirical research on the Treasury market, such as Green (2004), and Menkveld et al. (2008), in that private information is more prominent during announcement days than on non-announcement days in the Treasury market. This is because prescheduled announcements represent the majority of information arrival in the Treasury market and traders trade on their heterogeneous interpretation of public announcements. Nevertheless, the median PPIF in non-announcement days is similar in magnitude to that in announcement days. Thus private information on non-announcement days plays an important role in the price discovery process as well.

Figure 2 plots the intraday patterns of PPIF based on the Markov switching model for the 2-year note. The plots are similar for other maturities. PPIF peaks around pre-scheduled macroeconomic news announcement times, such as 8:30 AM and 10:00 AM. Consistent with the empirical evidence in Green (2004), Pasquariello and Vega (2007) and Menkveld et al. (2008) that private information is more evident around announcements, this finding offers initial evidence that the PPIF estimate captures the arrival of private information in the Treasury market. On days without announcements, the intraday pattern of information arrival is less distinctive. This is consistent with the intuition that private information could arrive at any time across the trading day. Nonetheless the PPIF measure is higher during mid-day and at the end of the trading day. The finding cannot be due to intraday seasonality as it has already been removed from return and volatility dynamics. Our conjecture is that during these times, particularly at the end of the trading day, it is more difficult to unwind positions. Thus dealers are more cautious of the possibility of trading against informed traders, resulting in less depth placed in the market. This in turn leads to a less liquid market and thus private information has a larger impact.

B. Private Information Flow and Price Persistence

In this section, we use price persistence as our main yardstick to examine whether PPIF actually captures private information arrival. If PPIF is truly informative, then a high PPIF should have price persistence because information arrival should have a non-transitional effect on price. Otherwise, there should be price reversal.

We first use a nonparametric test based on Kaniel and Liu (2006) to examine price persistence. A 5-minute interval is defined as having high (low) probability of private information arrival (hereafter high (low) PPIF) if the PPIF estimate is above (below) the 66th (33th) percentile of the PPIF estimates over the previous 5 days. If PPIF contains private information, the future return $R_{t+\Delta}$ should remain in the same direction as R_t when PPIF is high. The opposite should hold for the case of low PPIF: price change should reverse if it is not due to information arrival.

More specifically, let n^H be the number of same direction mid-quotes in the 30-minutes, 1-hour and 1-day following a high PPIF. Further, let P^H be the fraction of times that PPIF is high and n be the total number of quotes in the same direction in the 30-minutes, 1-hour and 1-day. Under the null hypothesis H_0 of equal informativeness under high PPIF and PPIF in the rest of the sample, the probability that out of these n quote revisions n^H or more are preceded by high PPIF is approximated by

$$1 - N[\frac{n^H - n \cdot P^H}{\sqrt{n \cdot P^H \cdot (1 - P^H)}}] \tag{10}$$

where N is the standard normal cumulative distribution function. We conduct the test on the overall sample, on announcement days and on non-announcement days. There are two alternative hypothesises. The first alternative hypothesis is that high PPIF is more informative. We reject the null in favor of this alternative if the p-value is less than, say, 5%. The second alternative hypothesis is that high PPIF is not informative. We reject the null in favor of this alternative if the p-value is more than, say, 95%. The test for low PPIF is defined in a similar way. Since there may be other announcements in the interim for a 1 day interval, we also control for the robustness of the test by including only observations without significant announcements [4] of Nonfarm Payroll, Consumer Confidence Index, ISM Index, Initial Jobless Claims, Leading Indicators, New Home Sales and Retail Sales in the next day interval. The results are qualitatively similar and are not shown for brevity purpose.

The results of the model are reported in Table 5. The first set of columns shows the p-values of the non-parametric test of price persistence following a high PPIF on all trading days, on announcement days and on non-announcement days, respectively. In all three maturities, the null hypothesis of equal informativeness is rejected at the 1% level in favor of the alternative that a high PPIF is more informative for all return horizons considered. Future return is significantly more likely to persist following a high PPIF. The results hold for all trading days, announcement days and non-announcement days. Thus the results indicate that a high PPIF is related to existence of private information and leads to permanent price change. Contrary to the results in the high PPIF group, the null hypothesis of equal informativeness of the low PPIF group is not rejected for the 2-year note. In fact, the null hypothesis is rejected in favor of the alternative that a low PPIF is not informative. Future return is significantly more likely to reverse following a low PPIF. The result indicates that a low PPIF is associated with the absence of private information and thus price change is less likely to persist or reverse as a result.

One disadvantage of the nonparametric test is that a cutoff criteria has to be imposed to define the high and low PPIF group. We next look at whether a higher PPIF is more likely to be related to a same direction future price change via a probit regression. More specifically, we create a dummy variable, D_{t+h}. It is equal to 1 if $R_{t+\Delta}$ is in the same direction as R_t, where Δ is set equal to a 30-minute, 1-hour or 1-day horizon. If PPIF measures are informative for future price changes, the likelihood of observing same direction price change increases with PPIF and PPIF should be significantly positive in the probit regression. We test this prediction by running probit regressions, where the dependent variable is D_{t+h} and the explanatory variable is PPIF. More specifically, the regression on non-announcement days is

[4] We define significant announcements with standardized surprise larger than or equal to 1

specified as

$$Pr(D_{t+h}|non-announcementdays) \;=\; f(\gamma_0 + \gamma_{PPIF} PPIF_t) \tag{11}$$

We also include announcement surprises as control variables on announcement days. The regression on announcement days is specified as

$$Pr(D_{t+h}|announcementdays) \;=\; f(\gamma_0 + \gamma_{PPIF} PPIF_t + \sum_{j=1}^{N} \gamma_j Sur_{j,t}) \tag{12}$$

Results of the probit regression are shown in Table 6. In terms of the predictive power of PPIF, results in Table 6 are consistent with findings in the nonparametric model. The PPIF measures are all positive and statistically significant for the 30-minute, 1-hour and 1-day horizons. The results hold for all trading days, announcement days, and non-announcement days. This implies that a higher PPIF is related to a higher likelihood of same direction price change. That is, PPIF captures existence of private information in the Treasury market. We also find evidence that the predictive power of PPIF drops over time. The predictive power of PPIF is strongest at the 30-minute horizon. But the magnitude of the coefficient capturing the impact of PPIF drops successively as we move to the 1-hour and 1-day horizons for both announcement and non-announcement days. Nevertheless the impact of PPIF remains significant over the 1-day interval.

C. Private Information Flow and Bond Price Variation

In this section, we examine how much explanatory power PPIF has for bond price variation by regressing bond price volatility against PPIF and other control variables. The idea that volatility is related to information arrival dates back to Clark (1973). Ross (1989) further shows that price volatility is perfectly correlated with information arrival in an arbitrage free economy. Other related work includes Andersen (1996), Andersen and Bollerslev (1997). In these models, there is no distinction between public or private information. Changes in volatility could be due to either type of information. Examining the explanatory power of PPIF allow us to explore the role of private information in affecting volatility.

On non-announcement days, the regression is performed using 15-minute realized volatility over the entire day. The explanatory variables include PPIF and liquidity shocks variables

$$\begin{aligned} RV_\tau &= \kappa + \kappa_{PPIF}\overline{PPIF}_\tau \\ &\quad + \kappa_{sprdshk} sprdshk_\tau + \kappa_{trdshk} trddshk_\tau + \kappa_{depshk} depdshk_\tau + \varepsilon_\tau \end{aligned} \tag{13}$$

where realized volatiity, RV_τ, is constructed from ln return over one-minute intervals and is defined as

$$RV_\tau = (\sum_{i=1}^{15} (\ln p_{\tau,i} - \ln p_{\tau,i-1})^2)^{1/2} \tag{14}$$

and $\overline{PPIF}$ is PPIF averaged over the corresponding 15 minute interval. The standardized shock to spread ($sprdshk_t$) is defined as:

$$sprdshk_\tau = \frac{\overline{spread}_\tau - \frac{1}{5}\sum_{j=1}^{5} \overline{spread}_{\tau,j}}{\sigma_{spread}}, \tag{15}$$

where $\overline{spread_\tau}$ is the average spread during the 15-minute interval and $\overline{spread_{\tau,j}}$ is the spread within the same 15-minute interval during the past five most recent non-announcement days. The standardized shock to overall market depth, $depshk$, and trading volume, $trdshk$, are defined similarly.

On announcement days, the regressions are performed over the two 15-minute intervals after the announcement time. In addition to liquidity shocks, we also include major announcement surprises to control for the effect of public information shocks. The purpose is to examine what role private information plays after public information shocks. The regression we estimate is specified as

$$\begin{aligned} RV_\tau &= \kappa + \kappa_{PPIF}\overline{PPIF}_\tau + \sum_{j=1}^{N} \kappa_j |Sur_{j,t}| \\ &\quad + \kappa_{sprdshk} sprdshk_\tau + \kappa_{trdshk} trddshk_\tau + \kappa_{depshk} depdshk_\tau + \varepsilon_t \end{aligned} \tag{16}$$

The results provide insights into the role played by private information, public information and liquidity in price variation. Consistent with existing studies, our results (see Table 7) show that volatility is positively related with public information shocks. For all three maturities we examine, realized volatility significantly increases with respect to announcement surprises in Change in Nonfarm Payroll, CPI and GDP. The effect is significant for both 15-minute intervals after announcement time. Liquidity shocks, on the other hand, play a marginal role immediately after an announcement. The three liquidity shock measures contribute to less than 1% of the variation in volatility immediately after announcements whereas their contribution rises to more than 15% of the variation in volatility in the second 15-minute interval after announcements.

Most importantly, for both announcement and non-announcement days, PPIF has significant explanatory power for bond variance, even after controlling for public information and liquidity shocks. Moreover, there is a higher sensitivity of bond price variation with respect to PPIF changes in the 5- and 10-year notes on both announcement days and non-announcement days. This is consistent with the notion that heterogeneous private information plays a more important role in markets with less liquidity. The results on announcement days further show that the sensitivity of bond price variation to PPIF decreases during the post-announcement period. This is consistent with Green (2004) finding that the private informational role of trading is highest immediately after an announcement. Comparing announcement days with non-announcement days, PPIF plays a more important role in volatility immediately after announcement. Nevertheless, PPIF remains significantly positive on non-announcement days and the magnitude of coefficients is similar to the second 15-minute interval after announcements.

D. Public Information Shocks and Heterogeneous Private Information

In this section, we further examine how heterogeneous private information interacts with public information shocks in driving the price discovery process on announcement days. We sort all announcements into terciles according to the absolute value of standardized announcement surprises. In each tercile, we calculate the average PPIF during the post-announcement period.

The second column in Table 8 shows the sample mean of PPIF of all news announcements (Panel A) and a selection of individual news announcements (Panel B to Panel E) over two 15-minute intervals after announcement. Interestingly, we observe a rather consistent U pattern in PPIF. That is, announcements with large or small absolute surprise are associated with higher level of private information flow in the market. The U-shaped pattern holds for both 15-minute intervals after announcements, though the level of PPIF in the second 15-minute interval is lower. On the other hand, when the magnitude of announcement surprise is at medium level, the level of private information flow is low. Our conjecture is that when announcement surprise is at medium level, there is less disagreement or divergent interpretation of how the announcement affects bond price among investors. When the magnitude of announcement surprise is large, there is likely more disagreement and diverse interpretation of the announcement information among investors. Interestingly, when the public information shock is small, the role of public information in the price discovery is relatively small and heterogeneous private information plays an important role driving bond prices. We also find that the level of private information varies among announcements. The PPIF level after the Change in Nonfarm Payroll remains consistently higher than, say, Consumer Confidence in the subsequent 30 minutes interval, though the absolute surprise level is similar across the two announcements

To confirm our conjecture, we also compute realized volatility and bid-ask spread in the post-announcement period for each of the terciles of absolute announcement surprise. The third and the last column in Table 8 shows the result on post-announcement realized volatility and bid-ask spread. The realized volatility and spread exhibit similar U-shaped pattern as the PPIF. Similar to the patterns of PPIF, realized volatility (spread) is higher (wider) with large or small information shocks for both 15-minute intervals after announcements. This is an indication that bond prices converge relatively slower when public information shocks are either high or low.

E. Private Information Flow and Market Liquidity

We next look at how liquidity is related to private information arrival and how it evolves subsequently. We offer two novel contributions to the literature. The first is that we are among the first to examine how liquidity evolves after private information arrival on non-announcement days. The issue is important because the nature of information arrival on non-announcement days is different in that both the timing and the context of private information is more uncertain than announcement days. This uncertainty could potentially impact the liquidity of the market. Our second contribution is that we consider a more complete set of liquidity measures. In addition to trading volume and bid-ask spread, we examine how the market depth at the best quotes, overall depth and hidden depth of the limit order book evolves after private information arrival. This is particularly important given the growing importance of limit order platforms in different asset classes.

We sort liquidity measures – trading volume, depth at the best quotes, overall depth, hidden depth at the best quote, overall hidden depth and spread– according to their associated PPIF at each 5-minute interval into 3 terciles and examine how liquidity measures are related to private information concurrently and in the subsequent two-hour interval. On announcement days, the sorting of PPIF is done at announcements times. On non-announcement days, all PPIF from 8:00 EST to 15:00 EST are sorted into 3 terciles. For each group, we report the sample mean depth at the best quotes ($DEP0$), overall depth ($DEPALL$), hidden depth at the best quotes ($HID0$), overall hidden depth ($HIDALL$), trading volume ($TRDQN$), and relative bid-ask spread ($SPREAD$) concurrently. We then calculate the average of these variables within each group in the next 30-minute interval, 30- to 60- minute interval, 60- to 90- minute interval , and 90- to 120- minute interval.

Table 9 reports the sorting results for the 2-, 5- and 10-year notes. Interestingly, our findings for trading volume offer a partial explanation for the contrasting finding in Green (2004) and Brandt and Kavajecz (2004): Green (2004) found that information asymmetry increases during announcements when trading volume is high in the 5-year note while Brandt and Kavajecz (2004) found that level of information asymmetry increases when market liquidity is low. We indeed find that trading volume is decreasing with PPIF on non-announcement days. At announcement times, trading volume varies with PPIF in a U-shaped pattern in the 5-year and 10-year notes. Trading volume is high in both the low PPIF group and the high PPIF group. It seems that when information asymmetry is high and the context of private information is uncertain on non-announcement days, market participants refrain from trading in the market and thus high information asymmetry is associated with a low level of trading volume. But when the context of information is known at announcements, traders who are confident about their interpretation of announcement information enter the market to trade and thus high information asymmetry is also associated with a higher level of trading volume.

Next we examine how market depth reacts to private information arrival. This issue has largely been unexplored in the literature because market depth information was generally not available before the transition to the electronic limit order book in the Treasury market. Depth on the best quote and overall depth is decreasing in PPIF concurrently at announcements and on non-announcement days. However, subsequent market depth evolves differently afterwards. Following high PPIF at announcements, both measures of depth increase in the subsequent two hours interval. This suggests that market participants post more limit orders on the book after resolution of information uncertainty at announcements. Following high PPIF on non-announcement days, however, both measures of depth either drop (in the case of the 2-year note) or remain stable (in the case of the 5- and 10-year notes) afterwards. This suggests that market participants refrain from posting limit orders when the nature of information is relatively uncertain on non-announcement days.

Hidden depth also reacts differently to private information on announcement days and on non-announcement days. Similar to market depth, hidden depth at the best quote and overall hidden depth on non-announcement days are decreasing in the level of private information but it increases with level of private information at announcement. The result seems to suggest that market participants place more hidden depth when the nature and timing of information arrival is known.

Spread is negatively related to PPIF in general. It is highest in the highest PPIF group both at announcement times and on non-announcement days. However, spread in the high PPIF group on announcement days reverts subsequently. The intuition is that once information unfolds in announcements, uncertainty quickly resolves in the treasury market. On the other hand, spread in the highest PPIF group on non-announcement days remains wide in the subsequent two hours horizon. Thus market participants refrain from posting aggressive quotes when the nature of private information arrival is unknown on non-announcement days.

Volatility varies differently at announcement times and on non-announcement days. Volatility increases with private information level at announcement times. It then drops in the subsequent two-hour interval. This suggests that uncertainty resolves quickly after announcements. However, volatility on non-announcement days exhibits a U-shaped pattern. It is high with both low and high levels of private information. Moreover, subsequent volatility drops only slightly. This suggests that volatility converges slowly after both high and low levels of private information on non-announcement days.

IV. Conclusion

In this paper, we examine the informativeness of order flow impact in the US treasury market. We identify estimates of the probability of information arrival(PPIF) over 5-minute intervals from a Markov switching model to examine private information on both announcement days and non-announcement days. Results of the Kaniel and Liu (2006) nonparametric test and a probit regression show that bond price changes associated with high PPIF exhibit non-transitory price impact over 30 minute, 1-hour and 1-day horizons on both announcement and non-announcement days. Although the impact of PPIF drops overtime, it remains significant up to the 1-day interval.

Consistent with existing studies, our results show that bond price variation is positively related to public information shocks. Liquidity shocks have a more significant effect on price variation on a non-announcement days. Most importantly, for both announcement and non-announcement days, PPIF has significant explanatory power for bond variation, even after controlling for public information and liquidity shocks.

We also finding interesting relationships between private information and subsequent liquidity dynamics. A higher level of private information is associated with a less liquid market on both announcement and non-announcement days. However, spread narrows and depth increases immediately after private information arrival on announcement days whereas spread remains wide and depth remains low on non-announcement days. Our findings suggests market participants refrain from posting aggressive quotes for a prolonged period when the nature of private information arrival is uncertain on non-announcement days.

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Table 1. Summary Statistics of Market Activities

This table reports the summary statistics of daily trading volume ($ billions), daily return volatility (%) of 5-minute returns based on the mid bid-ask quote from 7:00 a.m. to 5:00 p.m., relative spread ($\times 10,000$) and spread in ticks, average depth at the best bid and ask ($ millions), average depth in the entire order book ($ millions), average hidden depth at the best bid and ask ($ millions), and average hidden depth in the entire book during the sample period from January 5, 2004 to June 29, 2007. Spread and depth variables are averaged over 5-minute intervals of the trading day.

Variable	Mean	Median	StDev	Max	Min	Skewness	Kurtosis
Panel A: 2-year note							
Spread (in ticks)	0.86	0.84	0.07	1.55	0.78	3.80	25.81
Relative spread ($\times$ 10,000)	1.09	1.06	0.09	1.98	0.99	3.91	27.28
Trading volume ($ billions)	25.86	23.94	12.18	108.83	6.05	1.61	8.07
Return volatility (%)	0.07	0.06	0.04	0.57	0.03	5.04	45.65
Depth at the best bid and ask	547.09	509.98	334.78	1567.41	63.27	0.35	1.98
Hidden Depth at the best bid and ask	28.02	22.37	22.46	285.27	1.82	3.39	28.14
Depth of the entire order book	4092.43	3348.95	3136.67	11980.99	145.32	0.40	1.90
Hidden depth of the entire order book	70.81	54.72	61.36	561.15	3.89	2.72	14.87
Panel C: 5-year note							
Spread (in ticks)	0.99	0.94	0.18	2.40	0.81	3.48	20.62
Relative spread ($\times$ 10,000)	1.26	1.18	0.22	3.02	1.03	3.45	20.20
Trading volume ($ billions)	23.43	22.05	9.50	67.81	5.65	0.99	4.63
Return volatility (%)	0.18	0.16	0.10	1.66	0.06	5.98	67.36
Depth at the best bid and ask	107.13	107.50	51.64	237.99	20.90	0.32	2.09
Hidden Depth at the best bid and ask	6.24	5.09	4.40	39.37	0.14	1.85	9.20
Depth of the entire order book	1142.62	939.02	861.82	3819.46	81.98	0.84	2.91
Hidden depth of the entire order book	33.54	23.35	102.25	2883.53	1.22	26.03	723.85
Panel D: 10-year note							
Spread (in ticks)	1.87	1.80	0.24	3.35	1.60	2.69	12.21
Relative spread ($\times$ 10,000)	1.18	1.13	0.15	2.14	0.99	2.72	12.51
Trading volume ($ billions)	20.70	19.82	8.94	69.64	4.14	0.85	4.67
Return volatility (%)	0.30	0.28	0.15	1.92	0.11	4.48	37.74
Depth at the best bid and ask	108.71	108.39	49.54	243.36	16.46	0.23	2.29
Hidden Depth at the best bid and ask	5.16	4.32	3.75	30.31	0.13	2.24	11.75
Depth of the entire order book	1347.02	1117.87	910.89	3739.46	81.28	0.55	2.18
Hidden depth of the entire order book	31.53	25.90	26.08	257.22	1.29	3.21	21.84

Table 2. Macroeconomic News with Pre-Scheduled Announcements

This table reports the list of macroeconomic news included in our analysis. N denotes the total number of announcements during the period from 5th Jan, 2004 to 29th Jun, 2007. Day and Time denote, respectively, the weekday or day of the month and time (ET) of announcement. σ_{surprise} denotes the standard deviation of announcement surprises. $N_{|\text{surprise}|>k\sigma_{\text{surprise}}}$ denotes the number of announcements where the announcement surprise is more than k standard deviation.

News/Event	N	Day	Time	σ_{surprise}	$N_{\lvert\text{surprise}\rvert>\sigma_{\text{surprise}}}$	$N_{\lvert\text{surprise}\rvert>2\sigma_{\text{surprise}}}$
ADP payrolls	14	2 days before Change in Nonfarm Payrolls	8:15	n.a.	n.a.	n.a.
Business Inventories	42	Around the 15th of the month	8:30[a]	0.002266	10	2
Capacity Utilization	42	Two weeks after month end	9:15	0.00337	12	2
Change in Nonfarm Payrolls	42	First Friday of the month	8:30	78.29956	14	3
Chicago PMI	42	Last business day of the month	10:00	5.102023	13	3
Construction Spending	43	Two weeks after month-end	10:00	0.183016	1	1
Consumer Confidence	42	Last Tuesday of Month	10:00	4.663151	13	1
Consumer Credit	42	5th business day of the month	15:00	95.65377	1	1
Consumer Price Index	42	Around the 13th of the month	8:30	0.001507	16	0
Current Account	14	10 to 11 weeks after quarter-end	8:30	7.554709	5	0
Durable Orders	42	Around the 26th of the month	8:30	0.026315	14	2
Economic outlook	10	According to schedule	10:00[b]	n.a.	n.a.	n.a.
Existing Home Sales	41	On the 25th of the month	10:00	0.194676	14	3
Factory Orders	42	Around the first business day of the month	10:00	0.007144	10	3
FOMC Minutes	29	Thursday following the next FOMC meeting date	14:15	n.a.	n.a.	n.a.
FOMC rate decision expected	28	According to schedule	14:10	0	0	0
GDP Advance	14	3rd / 4th week of the month for prior quarter	8:30	0.006236	6	3
GDP Final	14	3rd / 4th week of second month following the quarter	8:30	0.004804	2	1
GDP Preliminary	14	3rd / 4th week of first month following the quarter	8:30	0.004605	2	1
Housing Starts	42	Two or three weeks after the reporting month	8:30	113.2129	10	4

Event	N	Day	Time	σ_{surprise}	$N_{\lvert\text{surprise}\rvert>\sigma_{\text{surprise}}}$	$N_{\lvert\text{surprise}\rvert>2\sigma_{\text{surprise}}}$
Industrial Production	42	Around the 15th of the month	9:15	0.003494	16	2
Initial Jobless Claims	182	Thursday weekly	8:30	16.29753	47	9
ISM index	42	First business day of the month	10:00	2.230697	13	1
ISM Services	42	On the third business day of the month	10:00	3.209909	16	1
Leading Indicators	42	around the first few business days of the month	8:30	0.001612	10	2
Monthly Treasury Budget	42	about the third week of the month	14:00	4.263603	6	3
New Home Sales	42	Around the last business day of the month	10:00	97.96987	12	3
NY Empire State Index	42	15th/16th of the month	8:30	9.61699	17	2
PCE	42	Around the first business day of the month	8:30	0.034868	5	5
Personal Income	42	Around the first business day of the month	8:30	0.003042	5	2
Philadelphia Fed Index	42	Third Thursday of the month	12:00	7.562973	17	1
Producer Price Index	42	Around the 11th of each month	8:30	0.23078	2	2
Retail Sales	42	Around the 12th of the month	8:30	0.121455	2	2
Semiannual Monetary Policy Rep	7	February and July annually	10:00	n.a.	n.a.	n.a.
Trade Balance	42	Around the 20th of the month	8:30	3.358122	12	2

[a] – Business inventories are announced at either 10:00 a.m. or 8:30 a.m. During 2003-2007, 29 announcements took place at 10:00 a.m. and 13 announcements took place at 8:30 a.m.

[b] – One testimony of Economic Outlook is released at 14:30 on 5th June, 2006.

Table 3. Estimation Results of the Markov Switching Model

This table reports the estimation results of the Markov switching model with state-varying order flow impact

$$\Delta p_t = \rho \Delta p_{t-1} + \mu + \mu_{PPIF} * D_t + \beta OF_t + \beta_{PPIF} * OF_t * D_t + \sum_{j=1}^{N} \gamma_j Sur_{jt} + \varepsilon_t \quad (17)$$

where OF_t is order flow measured as the number of bid trades minus the number of ask trades, $D_t = 1$ when $s_t = 2$ and $D_t = 0$ when $s_t = 1$. We include standardized announcement surprises Sur_{jt} for the following 12 important news and events (i.e., $N = 12$): Nonfarm Payroll, Consumer Confidence Index, ISM Index, Initial Jobless Claims, Leading Indicators, New Home Sales, Retail Sales, CPI, Durable Goods Orders, GDP Advance, and PPI. In addition, we set a dummy variable for FOMC. Estimates related to news announcements and events are not reported for brevity.

Parameter	2-year Note	5-year Note	10-year Note
μ	0.010	0.044	0.058
	(0.000)	(0.000)	(0.000)
μ_{PPIF}	0.052	0.027	-0.060
	(0.050)	(0.256)	(0.779)
σ	0.570	1.350	2.276
	(0.000)	(0.000)	(0.000)
β	0.014	0.021	0.038
	(0.000)	(0.000)	(0.000)
β_{PPIF}	0.116	0.117	0.186
	(0.000)	(0.000)	(0.000)
ψ_{11}	0.989	0.983	0.983
	(0.000)	(0.000)	(0.000)
ψ_{22}	0.418	0.704	0.718
	(0.000)	(0.000)	(0.000)
Announcement Surprises	...	...	...
(Included)			
Likelihood Function	-75098	-148436	-192485

Table 4. Summary Statistics of the Probability of Private Information Flow (PPIF)

This table reports the summary statistics of the estimates of the probability of private information flow (PPIF) based on the Markov switch model as in equation (8). The results are based on 5-minute data.

Maturity	Mean	Median	StDev.	Max.	Min.	Skew.	Kurt.	ρ_1	ρ_2	ρ_3
Panel A: All Days										
2-year	0.019	0.009	0.071	0.042	0.000	10.796	132.818	0.396	0.224	0.163
5-year	0.049	0.019	0.121	0.187	0.000	5.385	35.629	0.635	0.480	0.393
10-year	0.051	0.020	0.120	0.200	0.000	5.242	34.352	0.653	0.497	0.411
Panel B: Announcement Days										
2-year	0.020	0.009	0.078	0.045	0.000	9.943	111.673	0.395	0.223	0.161
5-year	0.053	0.019	0.131	0.218	0.000	5.045	31.125	0.627	0.475	0.389
10-year	0.055	0.020	0.130	0.235	0.000	4.906	29.949	0.647	0.491	0.407
Panel C: Non-announcement Days										
2-year	0.014	0.011	0.039	0.035	0.000	15.550	317.207	0.409	0.231	0.191
5-year	0.037	0.019	0.081	0.112	0.000	6.821	61.666	0.697	0.518	0.422
10-year	0.039	0.021	0.080	0.123	0.000	6.700	60.886	0.702	0.546	0.446

Table 5. Nonparametric Test of Permanent Price Impact

This table reports the p-values (%) of the nonparametric test of permanent price impact conditional on high (low) PPIF where high (low) PPIF estimates are defined as above (below) the 66th (33rd) percentile of the PPIF estimates over the past 5 days. Details of the nonparametric test can be found in Kaniel and Liu (2006).

	High PPIF			Low PPIF		
	30-min Ret	1-hour Ret	1-day Ret	30-min Ret	1-hour Ret	1-day Ret
Panel A: All Days						
2-year	0.00	0.00	0.00	100.00	100.00	99.94
5-year	0.00	0.00	0.00	100.00	100.00	100.00
10-year	0.00	0.00	0.00	100.00	100.00	100.00
Panel B: Announcement Days						
2-year	0.00	0.00	0.00	100.00	100.00	99.99
5-year	0.00	0.00	0.00	100.00	100.00	100.00
10-year	0.00	0.00	0.00	100.00	100.00	100.00
Panel C: Non-announcement Days						
2-year	0.00	0.00	0.00	92.17	83.21	69.43
5-year	0.00	0.00	0.00	100.00	99.92	99.81
10-year	0.00	0.00	0.00	100.00	99.99	98.35

Table 6. Estimation Results of the Probit Model for Permanent Price Impact

This table reports the estimation result of the probit model that relate the direction of future price change to PPIF estimates. The first column reports the results for all trading days, the second column reports the results for announcement days and the last column reports the results for non-announcement days.

	All Days			Announcement days			Non-announcement days		
	30 min	1 hour	1 day	30 min	1 hour	1 day	30 min	1 hour	1 day
Panel A: 2-year note									
γ_0	-0.552	-0.587	-0.667	-0.524	-0.558	-0.642	-0.691	-0.746	-0.761
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
PPIF	2.493	2.190	1.557	2.277	1.994	1.453	6.448	6.895	2.769
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Sur (included)				...	...	...			
Likelihood Function	-38334	-37648	-35970	-29205	-28740	-27473	-9048.0	-8809.6	-8446.7
Panel B: 5-year note									
γ_0	-0.053	-0.111	-0.230	-0.044	-0.100	-0.219	-0.086	-0.150	-0.266
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
PPIF	1.238	1.046	0.643	1.190	0.986	0.606	1.549	1.495	0.877
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Sur (included)				...	...	...			
Likelihood Function	-43020	-43022	-42472	-32404	-32441	-32080	-10605	-10566	-10379
Panel C: 10-year note									
γ_0	-0.115	-0.168	-0.272	-0.101	-0.154	-0.260	-0.170	-0.222	-0.316
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
PPIF	1.357	1.150	0.748	1.277	1.072	0.693	1.975	1.753	1.149
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Sur (included)				...	...	...			
Likelihood Function	-43006	-42897	-42225	-32633	-32584	-32116	-10352	-10290	-10092

Table 7. The Effect of Information Shocks, Liquidity Shocks, and PPIF on Bond Price Variations

This table reports the estimation results of the regressions of bond return volatility. The explanatory variables include PPIF, liquidity shocks and absolute announcement surprise for two post-announcement period (15-minute horizon, (0,15], and 15- to 30-minute horizon, (15, 30], after announcement), and PPIF and liquidity shocks for pre-announcement period and non-announcement days. The announcements includes Nonfarm Payroll (Nonfarm), Consumer Confidence Index (C.Confi), ISM Index (ISM), Initial Jobless Claims(Ini.Jobls.), Leading Indicators (Leading), New Home Sales (NewHome), Retail Sales (Retail), CPI, Durable Goods (Dur), GDP advance (GDPadv) and PPI.

Panel A: 2-year Note

	Pre-Ann.	Post-Ann . (0,15]	Post-Ann . (0,15]	Post-Ann . (15,30]	Post-Ann . (15,30]	Non-Ann.
κ	0.013	0.018	0.018	0.015	0.014	0.010
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
PPIF	0.021	0.057	0.056	0.023	0.022	0.030
	(0.286)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
DEPALLSHK	0.000		-0.001		-0.000	-0.000
	(0.854)		(0.094)		(0.000)	(0.152)
SPRDSHK	-0.000		-0.000		-0.000	0.000
	(0.913)		(0.703)		(0.091)	(0.117)
TRDQNSHK	-0.000		-0.000		0.001	0.002
	(0.568)		(0.537)		(0.000)	(0.000)
NonFarm		0.083	0.083	0.013	0.010	
		(0.000)	(0.000)	(0.000)	(0.000)	
C.Confi		0.003	0.003	-0.000	-0.001	
		(0.336)	(0.360)	(0.929)	(0.361)	
CPI		0.011	0.010	0.003	0.002	
		(0.002)	(0.003)	(0.007)	(0.064)	
Dur		0.003	0.003	0.001	0.001	
		(0.275)	(0.243)	(0.302)	(0.307)	
GDPadv		0.010	0.010	0.004	0.003	
		(0.011)	(0.010)	(0.004)	(0.008)	
ISM		0.005	0.005	0.001	0.001	
		(0.100)	(0.101)	(0.163)	(0.475)	
Ini.Jbls		0.003	0.003	0.001	0.001	
		(0.118)	(0.080)	(0.127)	(0.083)	
Leading		-0.002	-0.001	-0.002	-0.002	
		(0.558)	(0.629)	(0.034)	(0.069)	
NewHome		0.003	0.003	0.002	0.001	
		(0.363)	(0.345)	(0.063)	(0.217)	
PPI		-0.000	-0.000	-0.000	-0.001	
		(0.895)	(0.908)	(0.616)	(0.118)	
Retail		0.003	0.003	-0.000	-0.000	
		(0.496)	(0.506)	(0.723)	(0.841)	
Adj. R^2	-0.0063	0.5556	0.5558	0.2578	0.3790	0.2361

Panel B: 5-year Note

	Pre-Ann.	Post-Ann . (0,15]	Post-Ann . (0,15]	Post-Ann . (15,30]	Post-Ann . (15,30]	Non-Ann.
κ	0.026	0.039	0.040	0.032	0.030	0.021
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
PPIF	0.025	0.099	0.101	0.051	0.047	0.047
	(0.050)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
DEPALLSHK	0.001		0.001		-0.000	-0.000
	(0.018)		(0.489)		(0.380)	(0.000)
SPRDSHK	0.000		0.000		-0.000	-0.000
	(0.825)		(0.159)		(0.552)	(0.968)
TRDQNSHK	-0.000		-0.001		0.001	0.003
	(0.861)		(0.241)		(0.000)	(0.000)
NonFarm		0.228	0.231	0.034	0.027	
		(0.000)	(0.000)	(0.000)	(0.000)	
C.Confi		0.004	0.005	0.001	0.000	
		(0.640)	(0.556)	(0.739)	(0.854)	
CPI		0.023	0.024	0.010	0.008	
		(0.011)	(0.007)	(0.000)	(0.001)	
Dur		0.009	0.010	0.001	0.001	
		(0.253)	(0.191)	(0.602)	(0.794)	
GDPadv		0.019	0.020	0.009	0.008	
		(0.078)	(0.059)	(0.002)	(0.006)	
ISM		0.013	0.015	0.004	0.003	
		(0.123)	(0.076)	(0.068)	(0.194)	
Ini.Jbls		0.005	0.005	0.002	0.002	
		(0.244)	(0.237)	(0.071)	(0.074)	
Leading		-0.007	-0.007	-0.003	-0.002	
		(0.385)	(0.383)	(0.104)	(0.223)	
NewHome		0.006	0.006	0.004	0.004	
		(0.464)	(0.420)	(0.109)	(0.098)	
PPI		-0.002	-0.002	-0.001	-0.001	
		(0.767)	(0.792)	(0.756)	(0.481)	
Retail		0.020	0.019	-0.006	-0.005	
		(0.081)	(0.085)	(0.064)	(0.074)	
Adj. R^2	0.0168	0.5492	0.5501	0.3898	0.4383	0.2484

Panel C: 10-year Note

	Pre-Ann.	Post-Ann . (0,15]	Post-Ann . (0,15]	Post-Ann . (15,30]	Post-Ann . (15,30]	Non-Ann.
κ	0.045	0.070	0.062	0.057	0.052	0.038
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
PPIF	0.021	0.100	0.088	0.069	0.065	0.081
	(0.178)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
DEPALLSHK	-0.000		-0.001		-0.001	-0.001
	(0.818)		(0.597)		(0.000)	(0.000)
SPRDSHK	0.000		0.000		-0.000	0.000
	(0.953)		(0.718)		(0.147)	(0.059)
TRDQNSHK	0.000		0.002		0.002	0.005
	(0.254)		(0.000)		(0.000)	(0.000)
NonFarm		0.294	0.277	0.049	0.036	
		(0.000)	(0.000)	(0.000)	(0.000)	
C.Confi		0.008	0.005	0.003	0.002	
		(0.457)	(0.649)	(0.400)	(0.536)	
CPI		0.041	0.030	0.013	0.009	
		(0.000)	(0.011)	(0.002)	(0.018)	
Dur		0.011	0.005	0.001	-0.000	
		(0.264)	(0.628)	(0.807)	(0.971)	
GDPadv		0.041	0.036	0.016	0.014	
		(0.003)	(0.007)	(0.001)	(0.003)	
ISM		0.022	0.013	0.006	0.003	
		(0.047)	(0.251)	(0.120)	(0.401)	
Ini.Jbls		0.007	0.007	0.004	0.004	
		(0.186)	(0.233)	(0.039)	(0.029)	
Leading		-0.012	-0.008	-0.005	-0.003	
		(0.221)	(0.390)	(0.121)	(0.369)	
NewHome		0.000	-0.001	0.002	0.004	
		(0.993)	(0.944)	(0.520)	(0.293)	
PPI		0.001	0.001	-0.000	-0.000	
		(0.872)	(0.902)	(0.997)	(0.931)	
Retail		0.013	0.008	-0.007	-0.006	
		(0.369)	(0.580)	(0.196)	(0.227)	
Adj. R^2	0.0000	0.5354	0.5494	0.3050	0.4110	0.2719

Table 8. Information Flow Following News Announcements

This table reports how PPIF, return volatility, trading volume and spread are related to announcement surprises. We sort all news announcements into 3 groups according to absolute announcement surprises $|Sur|$ and report the sample mean of PPIF, return volatility, trading volume and spread in each group over the next 15 minutes interval, ($(0, 15]$) and 16 to 30 minutes interval, ($(16, 30]$).

	PPIF						Return Volatility					
$\|Sur\|$	2-year		5-year		10-year		2-year		5-year		10-year	
	$(0, 15]$	$(16, 30]$	$(0, 15]$	$(16, 30]$	$(0, 15]$	$(16, 30]$	$(0, 15]$	$(16, 30]$	$(0, 15]$	$(16, 30]$	$(0, 15]$	$(16, 30]$
Panel A: All news												
0.064	0.044	0.026	0.100	0.056	0.096	0.050	0.049	0.034	0.128	0.090	0.215	0.152
0.501	0.028	0.016	0.066	0.048	0.070	0.037	0.037	0.028	0.102	0.078	0.173	0.133
1.465	0.037	0.020	0.083	0.054	0.088	0.054	0.045	0.033	0.123	0.083	0.204	0.137
Panel B: Non-farm Payroll												
0.222	0.145	0.013	0.174	0.131	0.040	0.075	0.051	0.036	0.135	0.094	0.208	0.145
0.579	0.009	0.009	0.016	0.029	0.033	0.007	0.043	0.018	0.098	0.062	0.161	0.104
1.431	0.291	0.153	0.368	0.278	0.317	0.280	0.079	0.055	0.239	0.156	0.299	0.227
Panel C: Consumer Confidence												
0.220	0.008	0.005	0.051	0.020	0.059	0.018	0.019	0.014	0.059	0.040	0.086	0.063
0.584	0.003	0.008	0.045	0.014	0.064	0.009	0.018	0.013	0.052	0.039	0.094	0.064
1.490	0.027	0.028	0.086	0.064	0.053	0.016	0.024	0.021	0.066	0.053	0.114	0.084
Panel D: Initial Jobless Claims												
0.161	0.027	0.027	0.061	0.064	0.098	0.046	0.024	0.019	0.062	0.052	0.106	0.088
0.579	0.039	0.017	0.059	0.052	0.062	0.024	0.023	0.019	0.063	0.052	0.105	0.091
1.516	0.021	0.012	0.080	0.026	0.056	0.036	0.028	0.019	0.073	0.049	0.122	0.086
Panel E: Retail Sales												
0.011	0.029	0.009	0.042	0.021	0.111	0.047	0.027	0.015	0.066	0.044	0.099	0.080
0.033	0.021	0.011	0.098	0.014	0.066	0.027	0.025	0.018	0.066	0.056	0.116	0.100
0.381	0.019	0.008	0.149	0.126	0.120	0.065	0.032	0.023	0.104	0.066	0.180	0.111

$\|Sur\|$	Trading Volume						Spread					
	2-year		5-year		10-year		2-year		5-year		10-year	
	$(0, 15]$	$(16, 30]$	$(0, 15]$	$(16, 30]$	$(0, 15]$	$(16, 30]$	$(0, 15]$	$(16, 30]$	$(0, 15]$	$(16, 30]$	$(0, 15]$	$(16, 30]$
Panel A: All news												
0.064	621.4	425.6	503.8	372.7	458.7	334.2	0.084	0.083	0.096	0.095	0.179	0.177
0.501	589.0	438.1	502.4	384.6	459.6	360.7	0.083	0.082	0.094	0.095	0.177	0.175
1.465	682.0	501.2	516.6	411.7	478.6	369.5	0.084	0.085	0.099	0.095	0.178	0.179
Panel B: Non-farm Payroll												
0.222	1478.5	936.2	1005.5	789.3	892.4	665.7	0.083	0.081	0.104	0.116	0.191	0.190
0.579	1627.9	986.8	996.1	696.5	1034.3	723.8	0.083	0.083	0.095	0.083	0.162	0.177
1.431	1268.8	957.4	920.8	702.1	811.2	592.0	0.115	0.126	0.165	0.144	0.282	0.204
Panel C: Consumer Confidence												
0.220	644.4	413.6	491.3	366.7	413.4	320.7	0.078	0.080	0.095	0.080	0.168	0.172
0.584	491.4	439.1	474.9	391.5	494.5	385.0	0.076	0.078	0.093	0.093	0.179	0.160
1.490	529.1	376.2	428.5	363.6	371.7	284.3	0.082	0.080	0.097	0.095	0.186	0.183
Panel D: Initial Jobless Claims												
0.161	498.3	374.2	433.9	334.8	361.1	292.2	0.085	0.084	0.098	0.098	0.187	0.170
0.579	490.8	398.2	455.1	369.7	430.4	352.2	0.084	0.083	0.094	0.098	0.176	0.179
1.516	685.3	488.3	494.7	405.6	456.9	360.8	0.083	0.083	0.097	0.090	0.172	0.181
Panel E: Retail Sales												
0.011	667.5	420.4	506.5	327.3	487.4	335.7	0.078	0.084	0.090	0.120	0.171	0.184
0.033	665.2	448.9	571.1	418.4	578.5	408.7	0.086	0.088	0.098	0.092	0.181	0.185
0.381	956.7	651.5	729.7	493.8	740.4	504.5	0.082	0.084	0.091	0.097	0.203	0.179

Table 9. Relation between PPIF, Volatility and Liquidity Variables

The table reports how liquidity is related to PPIF. On announcement days, we sort PPIF at announcements into 3 equal groups. On non-announcement days, we sort PPIF at each 5-minute interval into 3 equal groups . For each group, we report the average of depth at the best quotes (DEP0), overall depth (DEPALL), hidden depth at the best quotes (HID0), overall hidden depth (HIDALL), trading volume (TRDQN), relative bid-ask spread (SPREAD), and volatility (VOLATILITY) at the same time interval (denoted by $(-5, 0]$). We then calculate the averages of these variables within each tercile group in the next 30-minutes interval $(0, 30]$, 30- to 60- minutes interval $(30, 60]$, 60- to 90- minutes interval $(60, 90]$, and 90- to 120- minutes interval $(60, 120]$. We use 8:30 announcements which are not followed by 10:00 announcements to get cleaner results (i.e. $(-5, 0]$ represents the 5-minute interval before an 8:30 announcement). On non-announcement days, data from 8:00a.m. till 3:00p.m. are used.

Panel A: 2-year note

Post-Announcement Period						Non-announcement Days					
PPIF	$(-5,0]$	$(0,30]$	$(30,60]$	$(60,90]$	$(90,120]$	PPIF	$(-5,0]$	$(0,30]$	$(30,60]$	$(60,90]$	$(90,120]$
A.1. TRDQN											
0.0002	1190.8	565.3	363.7	351.7	321.2	0.0003	372.3	243.6	224.2	208.6	196.5
0.0091	1059.9	522.5	354.9	302.5	319.5	0.0083	136.2	195.3	194.5	182.0	169.8
0.2509	978.5	572.2	360.5	334.6	281.5	0.0280	102.5	171.6	173.6	165.9	151.7
A.2. DEP0											
0.0002	542.4	714.1	780.0	729.1	767.5	0.0003	737.9	765.5	762.7	744.1	721.6
0.0091	471.7	630.8	710.9	749.4	733.7	0.0083	681.1	674.7	666.7	649.4	627.0
0.2509	343.1	459.0	505.5	516.2	499.8	0.0280	614.9	603.6	592.3	571.6	547.9
A.3. DEPALL											
0.0002	4911.1	5756.3	6152.4	5896.8	6136.3	0.0003	6017.3	6058.4	5971.1	5768.3	5535.1
0.0091	4150.3	4878.4	5255.8	5248.2	5370.1	0.0083	5198.9	5170.3	5057.4	4853.0	4602.2
0.2509	2865.1	3514.6	3824.5	3792.5	3805.4	0.0280	4597.9	4567.6	4424.4	4187.8	3923.5
A.4. HID0											
0.0002	3.1	11.4	17.0	22.7	14.0	0.0003	20.2	25.8	27.1	30.9	34.8
0.0091	4.4	7.7	15.0	19.8	18.8	0.0083	27.3	27.9	27.9	30.6	34.6
0.2509	8.9	11.5	13.8	16.9	11.4	0.0280	29.4	27.0	30.2	32.4	35.2
A.5. HIDALL											
0.0002	35.1	43.3	56.7	61.1	45.0	0.0003	72.2	76.6	78.4	83.1	87.9
0.0091	37.9	65.9	72.6	77.1	68.3	0.0083	68.5	71.1	72.3	75.3	79.8
0.2509	43.1	41.7	48.4	54.8	50.8	0.0280	67.8	67.1	71.4	73.5	75.9
A.6. SPREAD											
0.0002	0.083	0.082	0.082	0.081	0.082	0.0003	0.082	0.083	0.082	0.082	0.082
0.0091	0.083	0.085	0.082	0.084	0.082	0.0083	0.081	0.083	0.083	0.083	0.083
0.2509	0.086	0.084	0.083	0.081	0.082	0.0280	0.082	0.083	0.083	0.083	0.083
A.6. VOLATILITY											
0.0002	0.198	0.077	0.046	0.047	0.042	0.0003	0.043	0.036	0.034	0.032	0.030
0.0091	0.225	0.073	0.046	0.046	0.042	0.0083	0.022	0.033	0.032	0.031	0.029
0.2509	0.441	0.085	0.056	0.056	0.051	0.0280	0.038	0.032	0.031	0.030	0.028

Panel B: 5-year note

	Post-Announcement Period						Non-announcement Days				
PPIF	$(-5, 0]$	$(0, 30]$	$(30, 60]$	$(60, 90]$	$(90, 120]$	PPIF	$(-5, 0]$	$(0, 30]$	$(30, 60]$	$(60, 90]$	$(90, 120]$
B.1. TRDQN											
0.0019	814.6	471.8	342.4	346.1	328.7	0.0011	309.3	258.1	244.9	228.3	210.1
0.0259	659.1	425.3	333.2	282.0	281.1	0.0150	179.4	205.9	205.2	194.6	181.2
0.4542	731.5	454.7	308.9	309.4	271.3	0.0705	141.2	168.1	167.3	159.7	147.6
B.2. DEP0											
0.0019	102.6	130.6	152.7	144.5	152.9	0.0011	149.3	150.2	150.2	148.0	144.5
0.0259	93.3	109.0	113.1	112.4	114.4	0.0150	136.8	136.8	136.1	134.2	130.1
0.4542	73.1	88.4	105.8	98.6	103.5	0.0705	93.9	95.9	97.7	96.0	93.8
B.3. DEPALL											
0.0019	1433.1	1675.3	1839.3	1794.4	1903.0	0.0011	1885.3	1889.2	1859.0	1795.9	1724.1
0.0259	1017.8	1184.4	1266.3	1264.1	1286.7	0.0150	1646.3	1643.4	1609.3	1544.5	1470.0
0.4542	734.9	902.9	1026.5	1016.1	1041.4	0.0705	988.6	1001.8	994.7	954.3	899.6
B.4. HID0											
0.0019	0.0	2.1	3.0	3.0	3.3	0.0011	5.1	5.3	6.0	7.1	7.6
0.0259	0.0	2.1	2.8	4.5	3.0	0.0150	6.0	5.9	6.2	7.2	8.1
0.4542	1.0	1.2	3.5	3.3	4.3	0.0705	4.8	5.3	5.6	6.1	7.1
B.5. HIDALL											
0.0019	12.8	22.3	24.0	21.0	20.5	0.0011	33.7	35.1	37.1	39.4	40.0
0.0259	13.3	20.1	24.2	27.3	28.1	0.0150	33.2	34.2	35.3	37.1	39.0
0.4542	18.9	20.7	16.7	22.1	30.0	0.0705	29.9	31.5	33.9	34.4	36.4
B.6. SPREAD											
0.0019	0.092	0.092	0.092	0.093	0.091	0.0011	0.090	0.090	0.090	0.090	0.090
0.0259	0.095	0.097	0.092	0.094	0.091	0.0150	0.090	0.091	0.091	0.091	0.091
0.4542	0.110	0.105	0.101	0.102	0.099	0.0705	0.096	0.095	0.095	0.095	0.095
B.7. VOLATILITY											
0.0019	0.574	0.190	0.125	0.138	0.112	0.0011	0.105	0.095	0.091	0.087	0.081
0.0259	0.539	0.206	0.138	0.126	0.132	0.0150	0.072	0.092	0.089	0.084	0.080
0.4542	0.951	0.248	0.164	0.160	0.150	0.0705	0.119	0.104	0.099	0.095	0.090

Panel C: 10-year note

Post-Announcement Period						Non-announcement Days					
PPIF	$(-5,0]$	$(0,30]$	$(30,60]$	$(60,90]$	$(90,120]$	PPIF	$(-5,0]$	$(0,30]$	$(30,60]$	$(60,90]$	$(90,120]$
C.1. TRDQN											
0.0007	788.0	441.0	331.7	301.2	308.0	0.0015	278.7	233.2	218.0	204.0	186.3
0.0193	632.4	373.7	280.8	270.5	273.4	0.0175	147.1	172.5	171.9	161.8	153.1
0.4527	704.3	423.4	283.0	287.1	244.4	0.0783	114.5	133.6	136.3	133.8	124.1
C.2. DEP0											
0.0007	107.8	127.0	143.7	141.5	144.2	0.0015	148.8	149.7	149.5	147.8	145.2
0.0193	104.5	125.0	130.8	137.5	135.0	0.0175	128.5	130.5	130.3	128.8	126.4
0.4527	77.1	95.9	103.4	99.4	106.9	0.0783	94.6	93.2	94.8	94.7	93.7
C.3. DEPALL											
0.0007	1564.8	1855.9	2068.0	2022.1	2124.7	0.0015	2212.6	2222.9	2187.5	2111.4	2020.7
0.0193	1420.3	1657.9	1758.5	1748.4	1795.4	0.0175	1831.4	1823.4	1778.1	1697.5	1604.7
0.4527	966.6	1251.4	1390.6	1408.5	1427.0	0.0783	1138.5	1147.1	1125.1	1072.6	1012.1
C.4. HID0											
0.0007	0.6	2.3	2.5	3.7	3.5	0.0015	4.8	4.8	5.0	6.1	6.3
0.0193	0.3	2.1	2.5	2.4	3.1	0.0175	4.9	5.0	5.2	5.7	6.5
0.4527	0.6	1.4	1.7	2.3	2.3	0.0783	3.5	3.7	4.2	4.6	5.1
C.5. HIDALL											
0.0007	10.9	18.4	25.3	33.1	33.5	0.0015	39.5	40.6	42.2	43.7	44.6
0.0193	8.0	15.3	21.2	17.7	22.0	0.0175	34.6	35.3	37.2	40.2	42.9
0.4527	12.5	17.7	21.6	23.5	27.1	0.0783	24.4	25.9	28.8	31.0	31.7
C.6. SPREAD											
0.0007	0.185	0.180	0.183	0.179	0.173	0.0015	0.174	0.174	0.175	0.174	0.174
0.0193	0.187	0.177	0.178	0.181	0.178	0.0175	0.177	0.177	0.177	0.178	0.178
0.4527	0.191	0.191	0.179	0.179	0.180	0.0783	0.185	0.184	0.184	0.184	0.185
C.7. VOLATILITY											
0.0007	0.971	0.336	0.250	0.224	0.215	0.0015	0.181	0.170	0.162	0.155	0.145
0.0193	0.866	0.328	0.229	0.232	0.223	0.0175	0.129	0.161	0.154	0.147	0.140
0.4527	1.836	0.420	0.257	0.259	0.248	0.0783	0.205	0.175	0.169	0.162	0.154