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Fragilities in the U.S. Treasury Market: Lessons from the "Flash Rally" of October 15, 2014

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Fragilities in the U.S. Treasury Market: Lessons from the "Flash Rally" of October 15, 2014[1]

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Authorized for distribution by Daniel Hardy

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Abstract

Changes in the structure of the U.S. Treasury market over recent years may have increased risks to financial stability. Traditional market makers have changed their liquidity provision by increasingly switching from risk warehousing to risk distribution, and a new breed of market maker has emerged with the rise of electronic trading. The "flash rally" of October 15, 2014 provides a clear example of how those risks can materialize. Based on an in-depth analysis of the event—complementing the authorities' work—we suggest i) providing incentives for liquidity provision, ii) improving market safeguards, and iii) enhancing the regulation of the Treasury market.

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Author's E-Mail Address: abouveret@imf.org; pbreuer@imf.org; ychen@imf.org; djones2@imf.org, tsasaki@imf.org

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INTRODUCTION

The U.S. Treasury market is one of the largest and most liquid financial markets in the world, as well as one of the most important. Treasury securities are the bedrock of the financial system, serving as the pricing benchmark for many financial instruments. Apart from their critical role as the primary source of financing for the U.S. federal government deficit and the key instrument for the Federal Reserve’s implementation of monetary policy, Treasury securities are widely used as a risk-free investment instrument and to satisfy hedging, margining, and collateral needs of market participants. The majority of official international reserves are kept in Treasury securities, and during times of stress, the U.S. Treasury market is the premier destination for risk-adverse investors and safe-haven flows. The average daily trading volume in the Treasury market amounts to US$500 billion, more than twice that of U.S. equities (US$200 billion) and twenty times that of U.S. corporate bonds (US$25 billion).

The continuous functioning and smooth adjustment of the Treasury market is important to global asset markets and financial stability. Disruptions in the Treasury market could have large effects with potential macro-financial implications. Bouts of volatility could affect individual Treasury auctions, while extreme volatility could trigger margin calls with ripple effects throughout the financial system in the U.S. and in global markets, as investors sell assets to meet those margin calls.

The price swings and volatility seen in the Treasury market on the morning of October 15, 2014 were extreme and surprising, as they occurred in the absence of a major news event and were quickly reversed. The yield on the 10-year Treasury bond fell by 37 basis points (from 2.23 percent to 1.86 percent), but rebounded quickly and closed the day only 6 basis points below the previous closing level. Intraday moves of this magnitude are highly unusual and have been observed only on three occasions in the previous 25 years, all driven by significant policy announcements.

Yet, while the October 15 event does not appear to have had any lasting systemic consequences, it may be indicative of the structural changes that may hinder the continuous and smooth functioning of the Treasury market. Liquidity provision has been transformed by technological advances and changes to the business models of traditional market makers since the onset of the Global Financial Crisis (GFC). As a result, conventional measures of liquidity may overstate the true extent of available liquidity, which can vanish very quickly, i.e. there is an “illusion of liquidity”. During episodes of low liquidity, trades have a higher price impact than they would have had under normal liquidity conditions. Such a price jump can lead to destabilizing effects if it induces additional participants to trade in the same direction, thereby amplifying the initial shock (IMF (2015b)). Other episodes of price dislocation have been observed recently such as the surge in the Swiss Franc in January 2015 (IMF (2015a)), the Bund volatility in April-May 2015 or the equity flash crash on 24 August 2015.

These issues underlie the U.S. authorities’ Joint Staff Report on the October 15 events, which finds that High-Frequency Trading (HFT) firms played a dominant role in Treasury markets during the event window.[2] During the event window, the share of HFT

[2] JSR (2015) thereafter.

activity increased markedly, while HFT firms and dealers reduced their liquidity provision, resulting in large price moves.

This paper argues that the "flash rally" of October 15 was a reflection of structural changes in the Treasury market that had implications for market liquidity. Our analysis complements the Joint Staff Report by looking at the role of market safeguards during the event and proposing some measures to mitigate vulnerabilities in the Treasury market to minimize the probability of another "flash" event—potentially more damaging. The remainder of the paper is organized as follows: Section II describes the changes in the structure of the Treasury market; Section III takes a closer look at the events of October 15 2014; Section IV explores the factors that contributed to the "flash rally"; Section V discusses policy implications; and Section VI concludes.

I. CHANGES IN THE STRUCTURE OF THE U.S. TREASURY MARKET AND THEIR IMPACT ON LIQUIDITY

The U.S. Treasury market has experienced significant changes in market structure over the last decade. The rise of electronic trading and high-frequency trading firms and changes in banks' business models have led to changes in market liquidity. These structural changes provide the background against which the events of October 15, 2014 need to be analyzed.

A. Electronic trading in the Treasury market and the rise of new market makers

Technological advances and competition from new entrants have reshaped the structure of the U.S. Treasury market. Most of the trading of Treasury securities is done electronically, through "execution" strategies and increasingly through "automated" strategies. Execution strategies use technology to optimally execute an order by choosing the trading venue to send the order to, by slicing the order into smaller quantities, and/or by using an algorithm to minimize the price impact of trades. Automated decision-making trading strategies use algorithms to make investment decisions which are then executed electronically via an execution strategy.

Treasury futures and benchmark Treasury bonds have become almost exclusively traded on electronic platforms. This trend started more than a decade ago: Barclay et al. (2006) report that in 2001-2002, around 80 percent of benchmark Treasury bonds (recently issued or "on-the run") were traded on electronic platforms. Jiang et al. (2014) claim that by the end of 2004, more than 95 percent of inter-dealer trading of active issues occurred on electronic trading platforms. More recently, according to the Treasury Borrowing Advisory Committee (2013), benchmark Treasury bonds and futures are entirely traded on electronic platforms. As such, even bank-based broker-dealers have adopted electronic trading to varying degrees.

The widespread use of electronic trading in the Treasury market has affected broker-dealers. Over the past few years electronic trading platforms have introduced a range of new order execution types. By providing market participants with a wider range of order types, trading platforms have effectively increased the competition with traditional market makers, which provide customized services to their clients. For example, on the main U.S. Treasury trading platforms market participants can provide liquidity by placing limit orders or consume liquidity by placing market orders (Box 1).[3] More recent order types include "iceberg" orders where the size is hidden, and "fill or kill" orders, where the order is either entirely filled or cancelled. These automated services provided by trading platforms erode the traditional role of the broker-dealers and have allowed for the rise of firms specializing in high-frequency trading.

Box 1: Liquidity Consumption and Provision

Market liquidity is the ability to sell a security quickly, in sufficient quantity, with low cost and low price impact.

Liquidity is typically provided by traders who insert limit orders ("***passive***" orders), which are executed only when the pre-set price is met.

Liquidity is consumed by traders when they insert market orders (also called "***aggressive***" orders), which are executed immediately at the best available prices. Participants requiring immediate execution ("***immediacy***") place market orders. Since market orders can be executed at any price, they can have a large price impact when liquidity provision is low.

The concept of "***liquidity consumption***" and provision is closely related to the "***order book***". The order book is a continuously updated repository of outstanding limit orders (before the order is executed or canceled) and ranks available limit orders at a given price and quantity from the highest price to the lowest price. With this information, participants can gauge the market liquidity measured as the "***market depth***"— the total number of contracts offered on either side of the trade (i.e. the sum of the quantities attached to limit orders). [4]

Traders can also insert "***stop orders***", which are hidden orders for a given quantity and a threshold price. When the threshold is breached, those stop orders appear in the order book as limit orders at the best price. Stop orders are used to limit investors' losses or to lock in profits. By being hidden initially in the order book, they limit the ability of others to front-run them.

High-frequency trading (HFT) is estimated to account for more than half of the trading activity on benchmark Treasury bonds and Treasury futures.[5] In the cash market, HFT activity accounts for 40 to 50 percent of trading volumes (see Box 2 for a definition of HFT).[6] In the futures market, HFT activity is even higher: Tabb (2012) estimates that HFT accounts for more than 60 percent of volumes traded, in line with the estimate by the CFTC

[3] Trading in the Treasury market is either done among dealers, typically on electronic interdealer trading platforms such as BrokerTec and eSpeed (See Fleming (2009) for a presentation of BrokerTec), or between dealers and customers. The inter-dealer trading platforms have been opened to some non-dealers. The venue for U.S. Treasury futures is the Chicago Mercantile Exchange (CME).

[4] In Treasury futures market, only the top 10 price levels are visible to market participants.

[5] For Treasury bonds, the figures refer to interdealer trading platforms, excluding dealer-to-client transactions.

[6] Kite (2010) reports that HFT accounted for 45 percent of overall trading in U.S. Treasuries in 2010, while Jiang et al. (2014) find that HFT accounted for 40 percent of trades in 2011, and Light (2014b) estimates that HFT accounts for over 50 percent of the volumes in the Treasury market. JSR (2015) also points to HFT accounting for 50 percent of the volumes on control days.

in its Concept Release (CFTC (2013)). Recently, it has been reported that dealers only account for 14 percent of the volume traded by the top 10 trading firms on BrokerTec, against 86 percent for HFT firms (Smith (2015)).

Box 2: Definition of High Frequency Trading (HFT)

High frequency trading is a subset of automated (or algorithmic) trading strategies that involve the following features: i) proprietary trading; ii) very short holding periods; iii) submission of a large number of orders that are quickly modified or cancelled; and iv) proximity to the trading platform to minimize delays in the transmission of orders (latency). As a result of their speed, HFT strategies can react quickly to changes in the order book, implying that trades occurring just after an order book update (so called "***Reactive Trades***") are more likely to be done by HFT firms (see Appendix 2).

There is no consensus on the **measurement of HFT** among regulators, academics and market practitioners.[7] In practice, HFT can be identified using direct or indirect approaches or focusing on HFT strategies (see Bouveret et al. (2014) for a discussion and a comparison of approaches for European equities).

The **direct approach** relies on identifying the nature of the primary business of firms (see Brogaard et al. (2014) for an application to U.S. equities). This approach focuses on pure HFT firms and excludes HFT activity carried out by investment banks through their proprietary trading desks.

The **indirect approach** relies on trading and quoting patterns to identify HFT activity. A wide range of indicators can be used such as order-to-trade ratio, intraday inventories or lifetime of orders. For example, Kirilenko et al. (2014) define HFT as intermediaries with high volumes traded and low intraday inventories, while Jiang et al. (2014) look at the lifetime of orders as a proxy for HFT activity. Hasbrouck and Saar (2013) define the concept of 'strategic runs' to measure HFT activity. Strategic runs are a sequence of linked order book messages (rapid submissions, modifications and cancellations sent consecutively in less than one second). As such, the indirect approach requires defining thresholds associated with HFT.

An alternative approach is based on the **identification of HFT strategies** such as market making or statistical arbitrage implemented at the millisecond level. (Hagströmer et al. (2014)).

[7] Empirical studies are typically constrained by data limitations as available commercial data do not usually feature the identity of market participants and supervisory data are subject to confidentiality requirements.

B. Changes in traditional market makers' business models

Bank-based broker-dealers, the traditional market makers in the U.S. Treasury market, have changed their business mix to de-emphasize risk-warehousing in favor of risk distribution. When banks act as dealers they "warehouse" risk by using their balance sheet to meet the demand of their clients. In this role, bank inventories rise and fall depending on order flows and risk can reside on balance sheets for some time. By contrast, under the risk-distribution model, banks act in their broker capacity by matching buyers and sellers. They do not build significant inventories since they act purely as pass-through agents, sending their client orders directly to the market, leaving their balance sheets unaffected. As banks retreat from risk-warehousing, shock-absorbing pools of liquidity are reduced and, all else being equal, the tradable risk within markets circulates more and more quickly. This in turn may—at least in principle—contribute to a greater frequency of episodes in which the market experiences shortages of liquidity and volatility spikes.

The move by banks to a broker-based model may be linked to technology advancement and changes in their business models. The use of electronic trading platforms for fixed income markets makes it easier to match buyers and sellers by accessing a central limit order book on electronic trading venues, which can be done rapidly and efficiently by using automated trading and execution strategies. Changes in business models following the GFC have also led to a refocusing of banks' activities on their most profitable activities.

The shift to risk distribution is also driven by a decline in risk appetite. Following the GFC, dealers have become more conservative and less willing to take risks during periods of market stress. For instance, a recent study by Adrian et al. (2013) showed that during the 2013 "taper tantrum", dealers with more regulatory capital capacity actually sold off more of their inventories than those with tighter capital constraints. This suggests that risk appetite can play a larger role than regulatory constraints in the decision to shift away from risk warehousing to risk distribution.

In the banks' view, regulatory changes have had an adverse impact on market making. A range of regulatory developments resulting in higher capital and liquidity requirements have made risk warehousing more expensive, adversely affecting banks' ability to make markets. While it is too early to assess the cumulative impacts of regulatory changes, market participants have pointed to the Leverage Ratio (LR) in particular as having a significant impact by raising the capital cost of high volume/low margin activities such as market making and lending collateralized by low-risk assets (CGFS (2014), ECB (2015), IMF (2015a)).[8] By requiring that all assets, regardless of their relative riskiness, be funded with a minimum proportion of equity, the LR (and the Supplementary Leverage Ratio) incentivizes higher return/higher risk activities. Looking forward, the Net Stable Funding Ratio may also have an adverse impact on market making as it raises the relative cost of short term funding by requiring banks to have a stable funding profile. As a result, banks are running at higher

[8] While the US has long operated with a leverage ratio, the adoption of Basel III standards will raise capital standards further and restrict the types of equity that qualify as regulatory capital. Changes to US accounting principles, such as FASB 166 and 167, which alter the treatment of assets residing in funding vehicles and securitization pools, have closed loopholes that banks previously exploited to lower their reported leverage.

regulatory capital utilization and retaining less spare balance sheet capacity to handle the surges in assets that might result from distressed market conditions.

A long period of monetary accommodation by major central banks has further encouraged dealers to evolve towards the risk distribution model. In a low volatility environment, it is often more profitable to act as a broker rather than as a dealer: when expected risk levels are low, the premium paid to warehouse risk is correspondingly low and hence non-economical. As a result of technology, competition and changes in banks business models, there has been a longer-term reduction in the provision of liquidity by traditional market makers. As primary dealers have reduced their holdings of U.S. Treasuries since mid-2013 (Figure 1.1), their repo operations have also declined (Figure 1.2). As a result, turnover of U.S. Treasuries for primary dealers have fallen to less than 5 percent, compared to 10 to 12 percent before the GFC (Figure 1.3).

Figure 1. Primary Dealers in the Treasury Market

1.Net Inventories *(US$ billion)*

2. Amount of Repo Financing *(US$ billion)*

3. Turnover *(Percent, traded volume over free float)*

Sources: Federal Reserve Bank of New York; and IMF staff calculations.

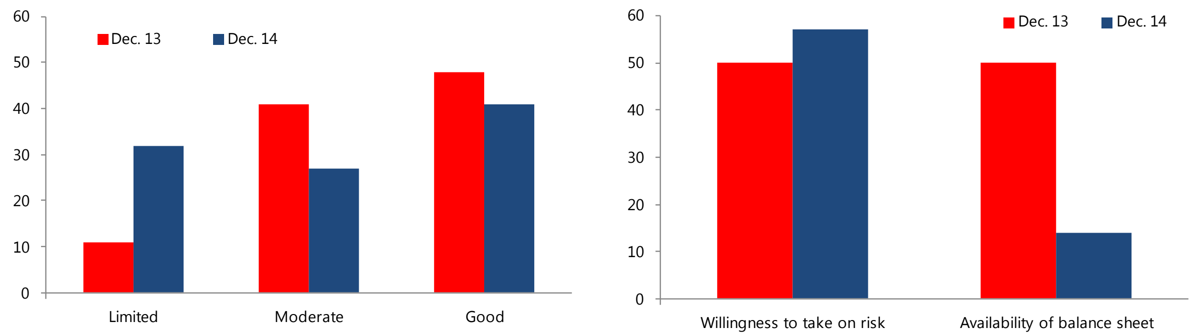
C. Implications for market liquidity

Changes in market structure and the associated rise of electronic market makers and the evolution of traditional market makers business models have transformed the provision of liquidity in the Treasury market. Traditional and new market makers operate with leaner inventories, affecting their capacity to make markets during volatile periods (IMF (2015a)). At the same time, they might also be unwilling to provide liquidity due to lower risk appetite and lower incentives (no contractual obligation with trading venues to make markets and less client accountability and reputational risk due to the anonymity of trading). For example, according to a recent ECB survey among large international banks and dealers, the proportion of respondents indicating a limited ability to make markets in times of stress has increased from 11 to 33 percent between December 2013 and 2014 (Figure 2.1), mostly due to the lack of willingness to take on risk (Figure 2.2). For example during the "taper tantrum", 43 percent of respondents reduced their market making activity due to lower willingness to take on risk, compared to 29 percent to risk management constraint.[9]

Figure 2. ECB Survey

1. Ability to Act as Market-Maker in Times of Stress
(Percent of respondents)

2. Reason for Inability to Act as Market-Maker in Times of Stress
(Percent of respondents)



Source: ECB survey on credit terms and conditions in euro-denominated securities financing and OTC derivatives markets.

Electronic market makers might be more reluctant to provide liquidity in stress periods. Raman et al. (2012) show that electronic market makers reduce their liquidity provision significantly when volatility is high. In contrast, professional traders tend to increase liquidity in the face of stress owing to a longer trading horizon. The study also finds that electronic market makers with longer trading horizons are less likely to withdraw liquidity provision in periods of market stress than their electronic peers. They explain these results by the fact that electronic trading allows participants to have considerably shorter trading horizons, and since electronic trading is anonymous, market participants have no incentives to provide liquidity under stress due to the lack of reputational effects. Korajczyk and Murphy (2014) show that HFT firms employing market making strategies on Canadian equities reduced their liquidity provision to large institutional trades by 42 percent during stress episodes while liquidity provision by designated market makers remained unchanged.

Surveys by the ECB suggest concerns by market participants regarding the role of electronic market makers. According to respondents, the growing use of HFT and automated trading is not a consistent source of liquidity during times of market stress. Under unfavorable market conditions, HFT and automated trading are seen as likely to amplify volatility and lessen market liquidity owing to the use of models that are sensitive to prevailing market conditions (ECB (2015)). Similarly, non-bank financial institutions are generally seen as liquidity takers under stressed market conditions because of their lack of market making obligations and low commitment to their client base.

[9] See ECB Survey on credit terms and conditions in euro-denominated securities financing and OTC derivatives markets, January 2014 (ECB (2014)).

II. A CASE STUDY: THE OCTOBER 15, 2014 "FLASH RALLY"

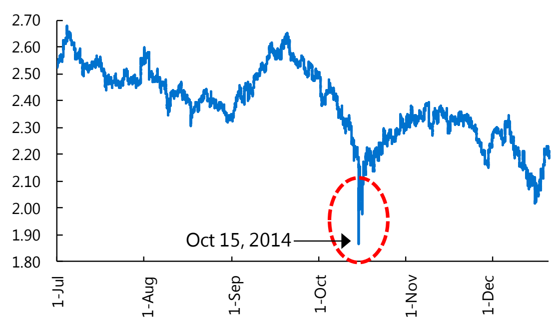
A. The events of October 15, 2014: a historical perspective

On October 15, 2014, U.S. Treasuries experienced one of the largest intraday changes in yields of the last 25 years. Yields on the 10-year bond fell 37 basis points during the morning session to an intraday low of 1.86 percent before rebounding quickly (Figure 3.1). The entire Treasury bond and futures curves were affected, with larger price moves for longer-dated tenors such as the 30-year bond. Movements were larger on only three other occasions, all driven by significant policy announcements (Figure 3.2).

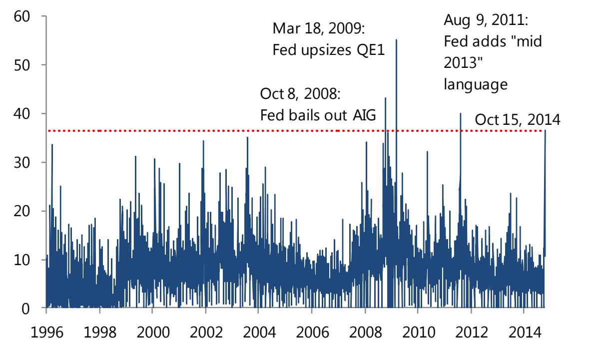
The intraday volatility of the U.S. Treasury market was associated with record high volumes in both cash and futures markets (Figures 3.3 and 3.4). Traded volumes on BrokerTec surged to US$946 billion on October 15, more than 40 percent higher than the previous record of US$662 billion during the May 2013 "taper tantrum".

Figure 3. The October 15, 2014 Flash Rally in the Treasury Market

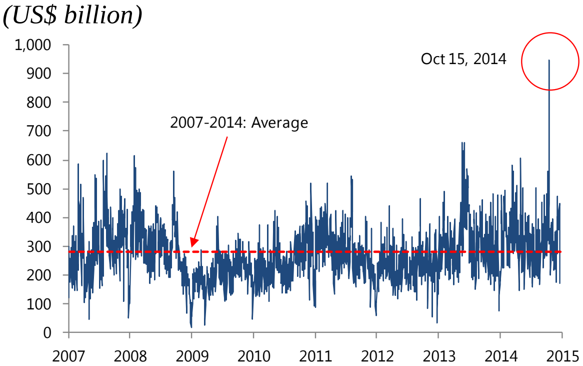
Treasury yields dropped suddenly and sharply…
1. Yields, U.S. 10-Year Treasury Bonds
(Percent)



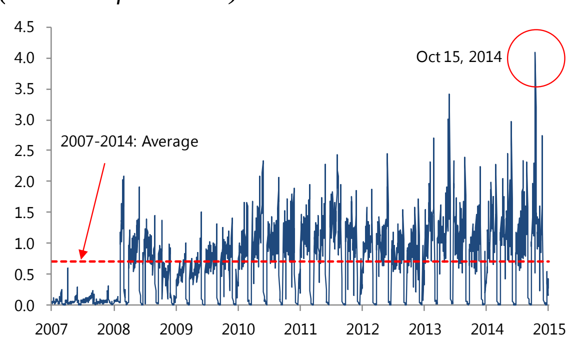
… with near record intraday change
2. Intraday Yield Changes, U.S. 10-Year Treasury Bonds *(Basis points)*



Volumes traded reached a record high in cash...
3. Volumes Traded on Brokertec, U.S. 10-Year Treasury Bond
(US$ billion)



...and futures markets
4. Volumes Traded on CME, U.S. 10-Year Treasury Futures
(Millions of contracts)



Sources: Bloomberg L.P.; CME DataMine; and IMF staff calculations.
Note: In panel 4, number of contracts traded on front-month U.S. 10-year Treasury futures. Spikes are due to the expiration of futures at the end of each quarter.

On the morning of October 15, trading conditions were seemingly normal as September retail sales data were expected to be released at 8:30. Ahead of the retail sales report, there were around 25,000 contracts offered for the 10-year Treasury futures at the top 10 prices, close to the average observed on previous days. As is common, liquidity vanished shortly before the 8:30 data release, as market participants reduced their orders to lessen their exposure to unexpected data. The data were modestly worse than the consensus expectation. However, the rebound of liquidity, which is typically observed after a news release, did not progress as usual.

Immediately after the report, liquidity started to recover for about 20 minutes, but unusually, failed to recover to the pre-announcement level. Instead, from 8:50 on, liquidity started to decline rapidly all the way through 9:30 when the total market depth was less than 20 percent of the pre-announcement level. Similar trends were also observed in the cash market. The reduction in liquidity was much larger than during the previous release of retail sales data (September 17) when liquidity recovered quickly and fully (Figure 4).

Other asset classes were also affected, in particular those closely related to U.S. Treasuries. Interest rate swaps—used by market participants to hedge their Treasury positions—fell 30 basis points between 8:00 and 9:40 and equity markets also experienced a significant decline, before rebounding quickly. However, equities, foreign exchange, and commodities did not exhibit large price moves.[10] The lack of large spillovers is prima facie evidence that the flash rally was not driven by fundamentals.

Following the event, liquidity provision remained subdued in the Treasury market. Market depth was very low the week after the event, falling by 40 percent in Treasury bonds and by more than 50 percent in Treasury futures (Figure 5). Since then, market depth has partially recovered in futures and cash markets but remains below long term averages.

Figure 4. Liquidity Around Retail Sales Releases, U.S. 10-Year Treasury Futures
(Market depth, number of contracts)

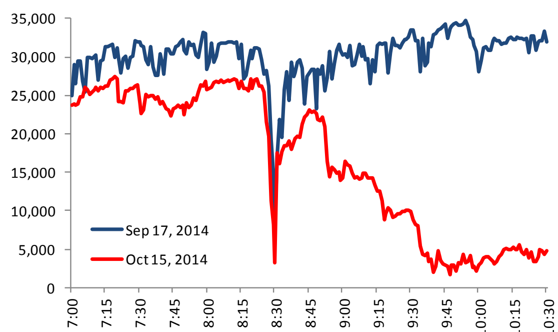
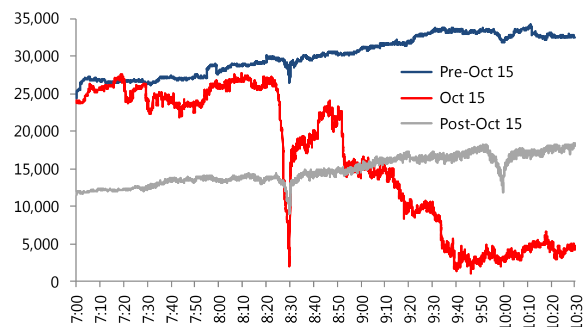


Figure 5. Liquidity Before and After October 15, 2014, U.S. 10-Year Treasury Futures
(Market depth, number of contracts)



Sources: CME DataMine; and IMF staff calculations.
Note: Market depth is the average of offer-side and bid-side market depth at top 10 bid prices. Pre-Oct 15 (post-Oct 15) market depth is the average of the 7 trading days preceding (following) Oct 15.

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[10] Between 9:30 and 9:40, the price of gold increased by 0.8 percent, the euro appreciated by 0.9 percent against the dollar and yields on 10-year German bonds declined by 4 basis points against 15 basis points for 10-Year U.S. Treasuries.

B. The events of October 15, 2014: a tick-by-tick analysis

It is useful to break down the events of October 15 into several phases. The flash rally appears to have started in the 10-year futures market and have reversed in the 30-year futures market.[11] Before the 8:30 retail sales report, there was ample liquidity in the market with relatively few trades. After 8:30, the price actions can be separated into three phases: (i) a steady rise in Treasury futures prices (falling yields) following the announcement between 8:30 and 9:33; (ii) a sudden sharp increase in prices between 9:33 and 9:40; and (iii) a sharp decline in prices until 10:00, when the market settled into more normal trading patterns amid low liquidity.

Following the retail sales report, a normal market reaction ensued between 8:30 and 9:33. Prices of Treasury futures started to increase (Figure 6.1) in response to the data. Prices continued to increase during the next hour, while market depth declined in consecutive steps from around 20,000 contracts offered at the 10 best prices to about half at 9:30 (Figure 6.2).[12]

The erosion of liquidity allowed the flash rally to take off at around 9:33 with a sudden increase in prices and further declines in market depth. A series of large aggressive buy transactions occurred at 9:33:45 (Figure 6.3, red circle), including the largest buy trade on that day for 1,000 contracts. These transactions consumed about 10 percent of the market depth available at the 10 best prices (Figure 7.1). These trades prompted liquidity to be depleted further to less than 5,000 contracts at the 10 best prices (Figure 6.2). While bid-ask spreads remained tight as there were offers at each price level, quantities offered were very small (Figure 6.1 and 6.2).

The sudden reversal of the flash rally appears to have been prompted by large sell orders that served as a resistance level to further price increases. At around 9:40, large sell limit orders for 30-year Treasury bonds and futures became visible in the order book, providing liquidity to buyers.[13] In the Treasury futures market, sell orders for more than 1,000 30-year contracts represented 40 percent of the 2,500 contracts offered to buyers at the 10 best prices (Figure 7.2). In the cash market, sell limit orders for US$8 million Treasury bonds represented more than 70 percent of the bonds offered to buyers. This additional liquidity created a resistance level, even though those orders were never executed against, and prices began to decline after a brief stabilization for five seconds. Subsequently, the price action spread across the entire Treasury curve in both cash and futures markets, and by 9:45, prices went back to their 9:33 levels amid very low liquidity and record high trading volumes, with some short-lived volatile episodes around 9:46 and 9:56.

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[11] Our analysis is mainly based on futures data. Data on the cash market made available by BrokerTec yield similar results but cannot be presented because of copyright issues.

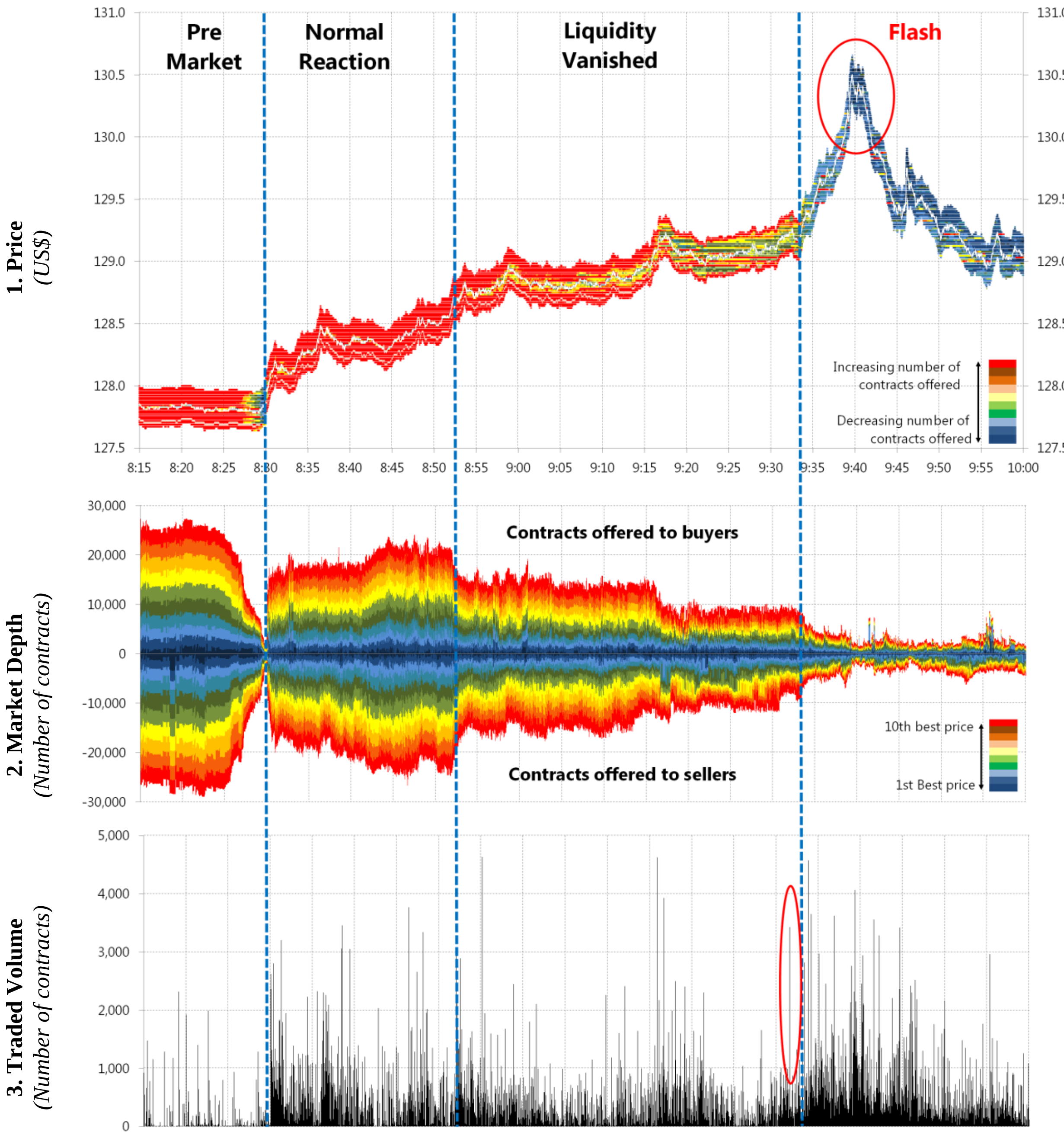
[12] See also Nanex (2014) for further analysis of the event using similar representation of the order book.

[13] Publicly and commercially available data does not permit to identify the type of firms placing those orders (e.g. HFT firms, banks or other type of participants).

Figure 6. The Event of October 15, 2014 in the Treasury Market: A Tick-by-Tick Analysis

Market liquidity evaporated at all price levels while bid-ask spreads remained tight

U.S. 10-Year Treasury Futures

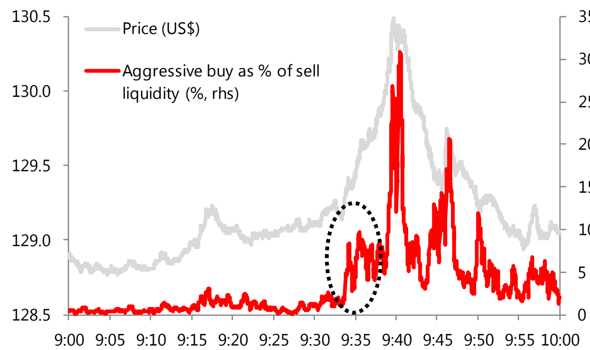


Sources: CME DataMine; Nanex (2014); and IMF staff calculations.

Figure 7. Build-up and Turnarond

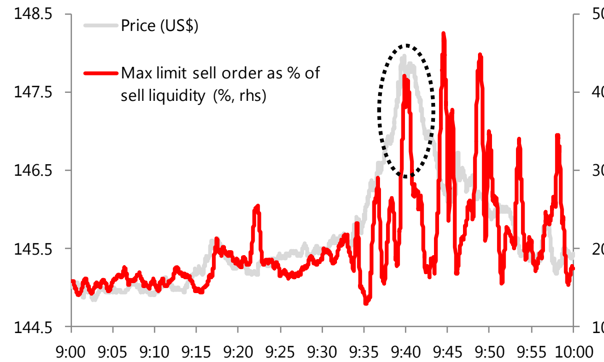
Large aggressive buys at 9:33 kicked off the flash rally

1. Order Imbalance, U.S. 10-Year Treasury Futures



Large sell orders at 9:40 served as price ceiling pivoting price actions downward

2. Order Imbalance, U.S. 30-Year Treasury Futures



Sources: CME DataMine; and IMF staff calculations.
Note: The ratio is calculated in the following three steps: (1) for each price level, calculate the number of all contracts offered for sale; (2) take the largest of (1); and (3) take the ratio of (2) to total sell-side market depth.

C. Market safeguards

Safeguards in the Treasury futures market did not prevent abnormal price movements on October 15. The CME has two main types of market safeguards: (i) a post-trade risk control that halts trading if price changes over one second are higher than a threshold ("velocity logic" functionality), and (ii) a pre-trade risk control that halts trading if the execution of a stop order would result in large price moves ("stop logic" functionality). In the past, U.S. Treasury futures have been subject to several trading halts, typically around news releases (see Appendix 1). However, on October 15, market safeguards were not triggered because (i) prices moved up rapidly but continuously between 9:33 and 9:40 (Figures 8 and 9), and, (ii) there was no execution of a single stop order which would have resulted in large price moves. The smoothness of the price increase (without "price gapping") suggests that there were contracts offered to buyers at each price level, although liquidity was scarce and some large trades were executed at multiple price levels.

Figure 8. Price and Trading Volume of U.S. 10-Year Treasury Futures
(25-millisecond intervals)

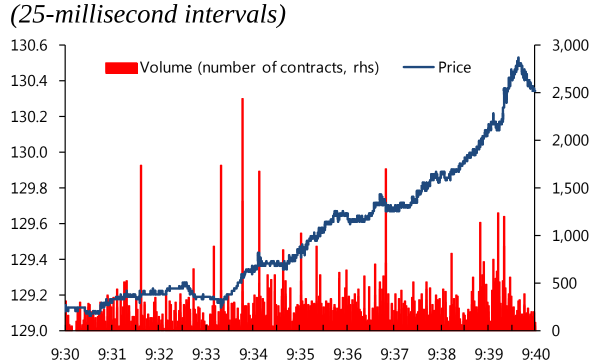
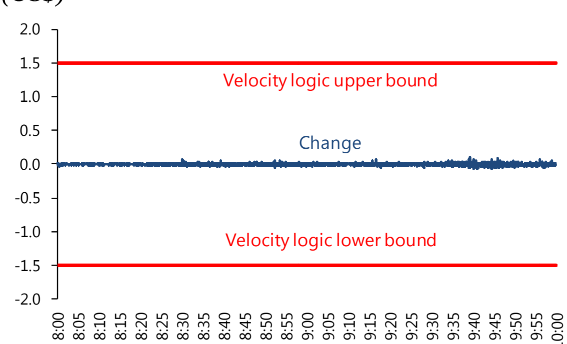


Figure 9. One Second Price Changes of U.S. 10-Year Treasury Futures
(US$)



Sources: CME DataMine; and IMF staff calculation.

III. What factors contributed to the flash rally?

The flash event occurred one hour after a relatively minor data release, in a context of generalized uncertainty. The analysis below seeks to identify factors that contributed to the initial market reaction, as well as those that amplified the shock and allowed the flash rally to take off.

A. Repositioning by hedge funds

The retail sales report on October 15 might have accelerated a repositioning by hedge funds that had been under way and possibly created the market conditions that allowed the flash event. The Federal Reserve had signaled earlier in 2014 that it would taper its purchases of U.S. Treasuries and mortgage-backed securities. This guidance, along with data which continued to show gradual strengthening of the U.S. economy, helped form a consensus in the market that the normalization of U.S. policy rates was approaching. Consequently, leveraged funds had been steadily reducing their net long positions in interest rate futures and assumed substantial net short positions to profit from the rise in rates. However, this consensus view began to be questioned in the weeks prior to October 15 due to a number of factors (including discouraging global growth data and reports of Ebola cases in the U.S.), all of which supported the possibility of 'safe haven' flows into U.S. Treasuries. Accordingly, U.S. Treasury yields declined 15 to 19 basis points across the 2- to 10- year maturities during the first two weeks of October. [14] For those investors who were still positioned for an upcoming rate hike, particularly those with leveraged positions, the possibility that Treasury yields could decline further raised the specter of potentially significant losses. As a result, many hedge funds might have had to reduce their short positions in Treasury securities to avoid the risk of further losses.

On the morning of October 15, hedge funds covered their short positions by buying Treasuries. According to a recent survey among dealers by the Federal Reserve (FRB (2015)), around two-thirds of respondents indicated that hedge funds were net buyers of Treasuries between 8:30 and 10:00 AM (Figure 10.1).

However, repositioning by hedge funds cannot account for the flash dynamics observed between 9:30 and 10:00. First, most of hedge funds' repositioning in U.S. Treasury futures occurred in September (Figure 10.2), without any significant price impact. Second, the flash dynamics occurred more than one hour after the retail sales report, in other words, well after the normal time frame for news-driven market reaction.[15] Third, repositioning was

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[14] Additionally, hedge funds facing losses from a canceled merger may have begun to close short positions in Treasuries, spurring demand. A number of prominent hedge funds had acquired sizeable shares in the firm Shire to benefit from its merger with AbbVie. On 15 October, following changes by the U.S. Treasury to deter so-called tax-inversion deals such as the proposed merger, AbbVie's management announced that it would reconsider the merger. The failure of the merger resulted in an estimated unrealized loss of US$1.2 billion (Devasabai (2014)). Losses incurred on this position may have spurred multi-strategy hedge funds to reduce risk and to unload liquid positions to meet potential redemption requests.

[15] Simon Potter, executive vice president of the Federal Reserve Bank of New York also stressed this point in a recent speech: "*Yet these factors* [hedge funds repositioning following a modest surprise in U.S. retail sales] *are less convincing as explanations of the round-trip in yields witnessed more than an hour after the data release*." (Potter (2015)).

directional, resulting in buying pressure, and thus cannot explain the reversal observed around 9:40 AM.

Figure 10. Hedge Fund Repositioning

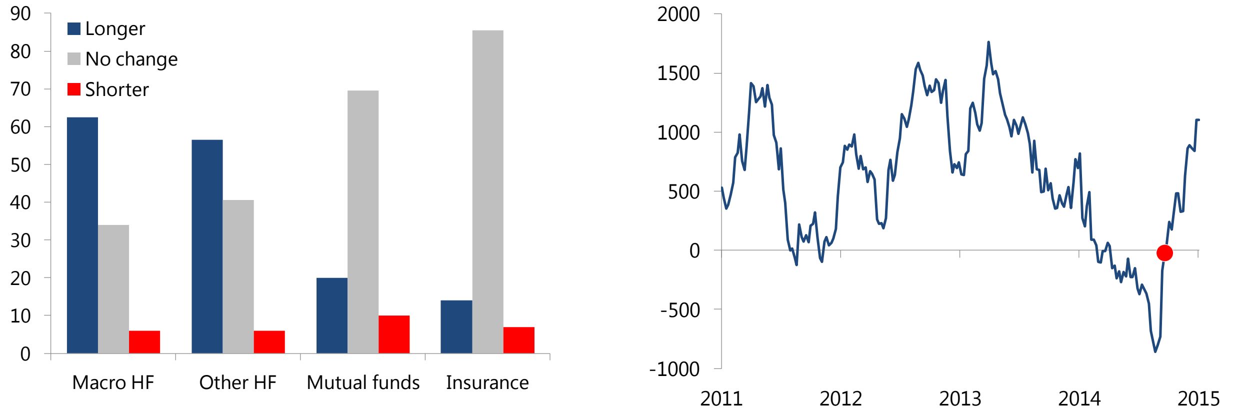
Hedge funds covered their short positions by buying Treasuries…

1.Hedge Funds: Change in Net Positions in U.S. Treasury Cash and Derivatives on October 15, 2014 between 8:30-10:00 AM *(Percent of respondents)*

…but repositioning by leveraged funds towards delayed Fed lift off was well under way.

2. Leveraged Funds: Net Positions in U.S. Treasury Futures

(Thousands of contracts)



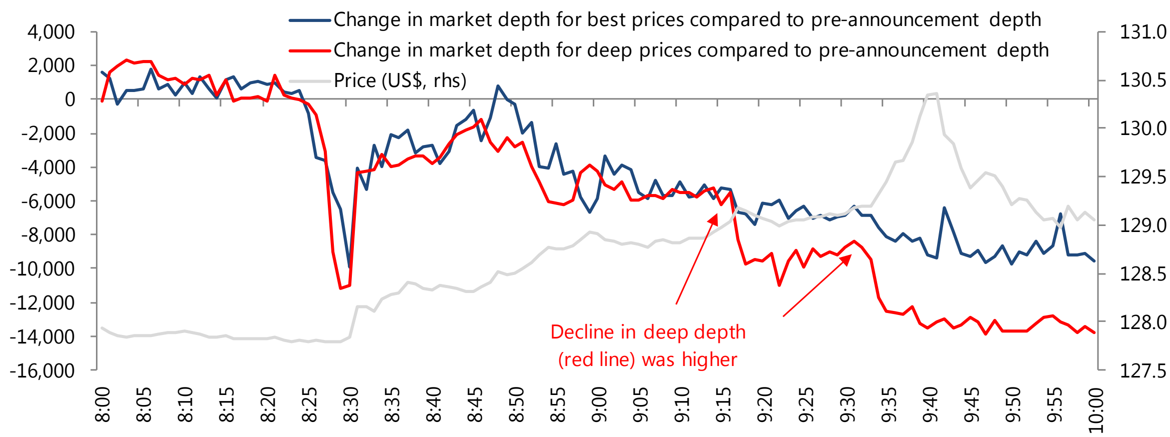
Sources: Board of Governors of the Federal Reserve System; CFTC; Bloomberg L.P.; and IMF staff calculations.
Note: The red dot corresponds to the positions during the week of October 15, 2014.

B. Withdrawal of liquidity providers

Market depth was severely reduced during the event as liquidity providers did not replenish the liquidity that was consumed. Limitations on publicly and commercially available data do not allow the analysis of individual market participants. However, as noted earlier, liquidity provision can be gauged by looking at the depth of the order book at different price levels. While HFT firms typically provide liquidity close to the best prices, liquidity provided deeper in the order book (away from the best prices) is more likely to be coming from dealers.[16] On October 15, the reduction in market depth was higher for orders deep in the order book (6 to 10 best prices), compared to orders close to best prices (1 to 5 best prices). In particular, around 9:10, depth of deep orders declined more than for orders close to the best prices (Figure 11). This can be interpreted as indirect evidence that dealers reduced their liquidity provision more than HFT firms during the event. According to the JSR (2015), during the event, "*bank-dealers flows were not indicative of significant market making activity*", and "*bank-dealers that remained present in the market […] only provided limit orders at a substantial distance from the top of the book*" (JSR (2015)).

[16] It has been documented that HFT firms tend to insert orders close to the best prices (Brogaard (2010), JSR (2015)).

Figure 11. Liquidity in 10-Year Treasury Futures



Sources: CME DataMine; and IMF staff calculations.

Risk warehousing practices by traditional market makers may also have amplified price swings. Dealers typically internalize a significant share of their clients' orders, i.e. they net client order against their inventory (risk warehousing) rather than sending their orders to the cash market. [17] However, when faced with significant buying pressure, dealers might have reduced their internalization and instead sent their client orders directly to the market, thereby amplifying the buying pressure. There is no direct evidence of this behavior due to the lack of available data with respect to dealer-to-client activity. There is indirect evidence from data on consecutive trades. Typically, traders break up their orders into smaller ones to limit their price impact, which results in a series of consecutive trades on the same side of the order book. For example, dealers buy securities from their clients until they reach their inventory limit. When this limit is reached, they reduce their accumulated inventory by selling the securities on trading platforms, resulting in a series of consecutive sells.[18] Indeed, on control days (pre-October 15), there was an average of 20 consecutive trades on the same side (buy or sell).[19] However, on October 15, this figure declined to less than 10, consistent with a reduced warehousing of clients orders, as dealers might have 'dumped' their clients orders directly to the interdealer market. A similar pattern was observed during the May 6, 2010 equity flash crash (SEC-CFTC (2010)).

C. High frequency trading

Several proxies for HFT indicate higher activity during the event. [20] For example, the number of order book updates on October 15 was significantly higher during the event window than October 2, another day with macroeconomic news releases in the morning

[17] Light (2014a) estimates that dealers internalize 50 percent of the client orders flow.

[18] In practice, dealers can also manage their inventories by taking opposite positions in futures market.

[19] Computed as the simple average of consecutive buys (or sells) between 8:30 and 10:00.

[20] Hereafter, HFT stands for all types of automated trading strategies. That is both proprietary trading strategies by investors who are deemed as high frequency trading firms and other automated trading strategies, including algorithmic trading strategies that focus on the maximization of trade execution efficiency are encompassed.

(Figure 12). Order book updates surged from 10,000 updates per minute before the event to a peak of 30,000 updates around 9:45 AM on October 15. This proxy indicates a high level of HFT activity, as manual traders do not have the capacity to update their orders as quickly as algorithms.

Figure 12. Order Book Updates per Minute, U.S. 10-Year Treasury Futures

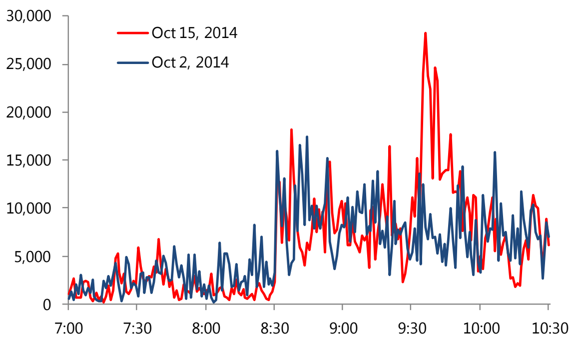
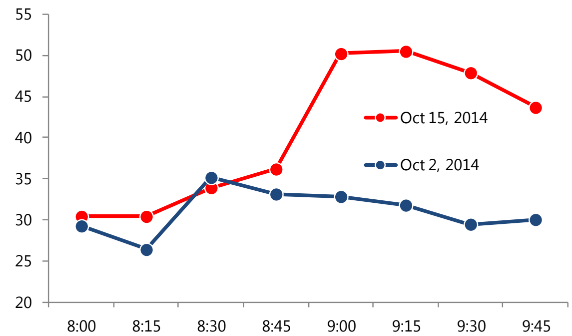


Figure 13. Share of Trades For 1 Contract, U.S. 10-Year Treasury Futures
(Percent)



Sources: CME DataMine; and IMF staff calculations.

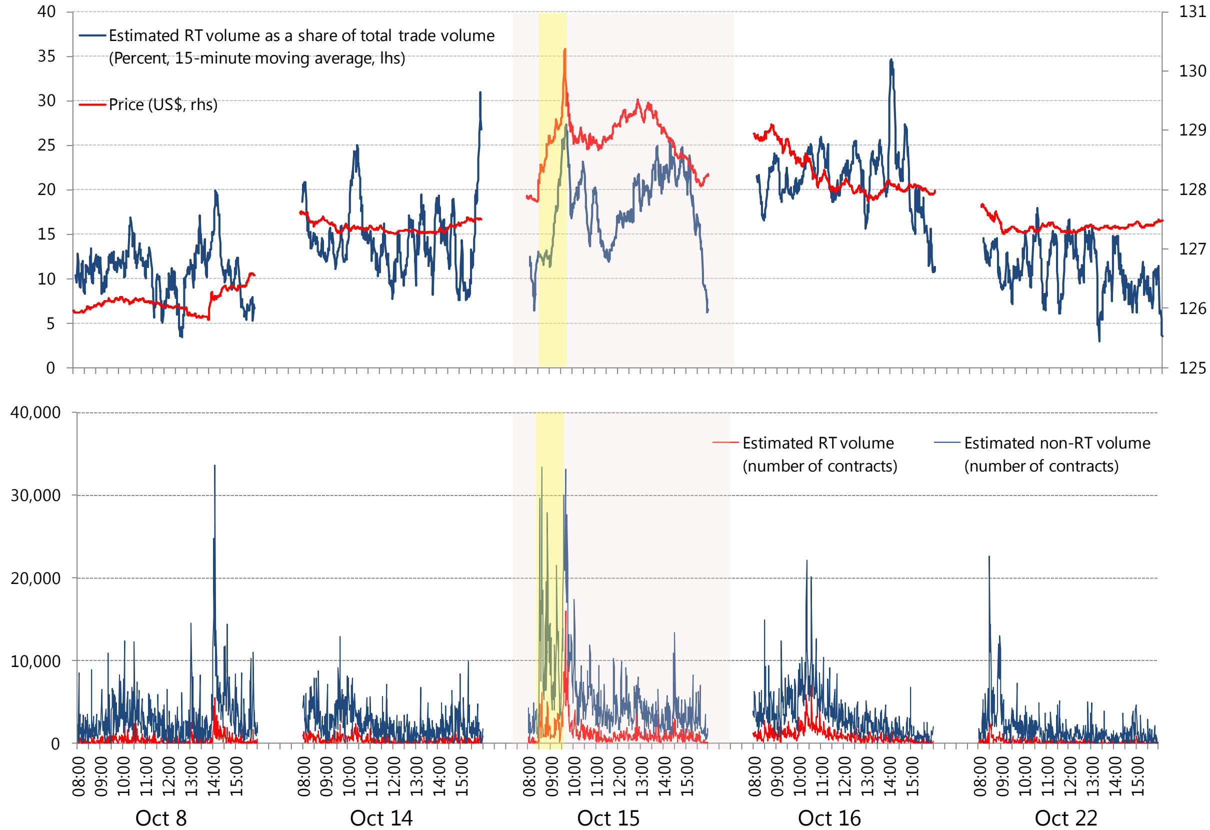
Trading took place during the event in unusually small clips, also pointing to higher HFT activity. HFT firms do not typically take large positions but rather execute multiple trades for small quantities. Therefore, a higher number of smaller trades is consistent with higher HFT activity. During the event, around half of the trades were for only one contract, more than 20 percentage points higher than on October 2 (Figure 13).[21]

Reactive trades, another proxy for HFT activity, also increased during the event. As it is impossible to directly observe the level of HFT activity from commercially available data, we infer the level of HFT activity by looking at reactive trades (RTs), defined as market orders which are executed in reaction to an update of the order book. RTs constitute a subset of HFT strategies and therefore our estimates are a lower bound of HFT activity.[22] The estimated share of RTs increased after 9:00 on October 15 concurrently with the gradual depletion of market depth (Figure 14). At the peak, more than 16,000 contracts are estimated to be RTs between 9:39 and 9:40, more than 25 percent of the entire volume traded during that period.

[21] 10-Year Treasury futures contracts have a notional value of US$100,000.

[22] We estimate the volume of RTs by assigning to each trade a probability of being an RT based on the time elapsed between the order book update and the trade. If a trade occurs very quickly after an order book update, then there is a higher probability that it is a RT. This method is in line with Jiang et al. (2014), who identify a trade that occurs within 1 second of an order book update as a high frequency trade. However, our method corrects the upward bias in their measurement that arises when order book update occurs very frequently as on October 15. Details are provided in Appendix 2.

Figure 14. Estimated Volume Traded in RTs and non-RTs
(U.S. 10-Year Treasury Futures, Minute-by-Minute)

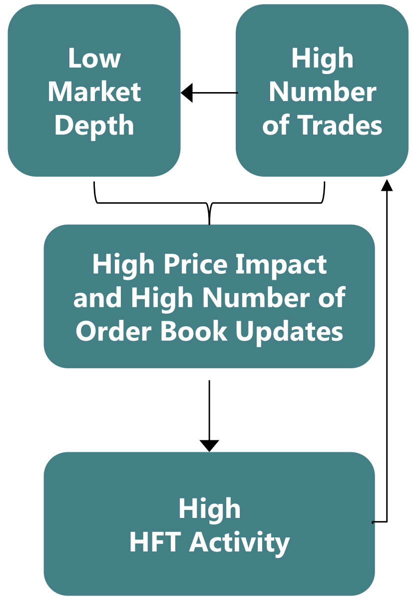


Sources: CME DataMine; and IMF staff Estimates.
Note: RTs refers to reactive trades.

The combination of high HFT activity and low market depth likely amplified the price dynamics. High HFT activity by itself does not necessarily result in significant price changes as shown by spikes on October 8, 16, and 22 (Figure 15). The indirect evidence we have gathered suggests that it was the combination of the withdrawal of liquidity provision by traditional market makers and HFT firms and the rise in aggressive HFT activity which generated the flash dynamics. Amid low depth, each trade resulted in a higher price impact and large number of order book updates, thereby inducing more RTs: this positive feedback loop may have contributed to the increase in order book updates and HFT activity, further depleting market depth (Figure 15).[23]

[23] A similar pattern was also observed during the equity flash crash on May 6, 2010, as detailed in appendix 3.

Figure 15. Positive Feedback Loop



D. Authorities' analysis of the event

In a report released on 13 July 2015, the U.S. authorities identified the sharp decline in liquidity and the role of HFT activity as main contributors to the flash rally (JSR (2015)). Using granular data, the report shows a significant reduction in market depth during the event. This is attributed to HFT firms and dealers reducing their liquidity provision. HFT firms reduced the quantities offered, and broker-dealers increased their spreads and removed their offers for very brief periods (fraction of seconds). During the event, the share of trading done by HFT firms is shown to have increased markedly to about 70 percent of trading activity (against 50 percent on control days), as HFT firms were aggressively buying during the price rise and selling during the decline (JSR (2015)). The report also confirms the positive feedback loop mechanism described in the previous section, with HFT firms (and algorithms) trading with each other very quickly and on a large scale.

The JSR (2015) also points to latency issues and self-trades among participants. At the beginning of the event window, there was a surge in message traffic sent to CME matching engines which resulted in an increase in latency. While it is not possible to determine whether this was linked to market manipulation, our interpretation is that the exchange's IT systems could be exposed to operational risk which could impact orderly trading.[24] The large number of self-trades during the event, and to a lesser extent on control days, also raises

[24] A manipulative strategy called "Quote stuffing" aims at sending a large number of messages to the matching engine in order to slow it down and get an edge against competitors. CME considers quote stuffing a disruptive practice, as detailed in Rule 575 published in August 2014 (CME (2014)).

concerns as market participants might have executed self-trades in order to manipulate prices ("wash sales"). [25]

The JSR (2015) makes a series of recommendations regarding the regulation, inter-agency oversight and monitoring, and risk management practices of the Treasury market. The latter recommendation echoes a recent initiative by the Treasury Market Practices Group (TMPG) which has issued a Consultation Paper aimed at reinforcing best practices in the Treasury market (TMPG (2015)). The JSR (2015) also supports a review of the current regulatory framework for Treasury securities and a study of potential registration requirements for HFT firms active in the Treasury market.

IV. MEASURES TO STRENGTHEN THE U.S. TREASURY MARKET

The resilience of the Treasury market could be strengthened to prevent the occurrence of similar events in the future. To achieve this, measures could be considered in three broad areas: (i) providing incentives for liquidity provision, (ii) improving market safeguards, and (iii) enhancing the regulatory framework of the Treasury market.

A. First line of defense: provide incentives for liquidity provision

Mechanisms that ensure the permanent provision of liquidity would be helpful to prevent flash events. A steady replenishment of the liquidity that leaves the market would ensure that there is no gradual erosion of liquidity. In such deep and liquid markets, individual trades only have a limited price impact. Hence, liquidity provision can be considered a public good that benefits all participants of a market and related markets.

Authorities and operators could consider introducing designated market makers on the Treasury cash and futures markets. [26] Designated market makers (DMMs) have contractual obligations to provide liquidity for a list of securities on a trading venue, in exchange for privileges (such as financial incentives). They can supply liquidity on a continuous basis, thus providing stability to financial markets. A recent Bank of England publication noted that "*properly calibrated DMM schemes can help prevent the virtuous circle of efficiency and liquidity from degrading into a vicious circle of mispricing and illiquidity*" (Benos and Wetherilt (2012)).[27]

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[25] During the event there was a surge in the amount of self-trades (a firm trading with itself), reaching up to 33 percent of trading volumes in the 5-year note. As explained in the Joint report, self-trading may reflect unlawful conduct, although the report does not take a position, stating that "*the report is not making any findings on the legality of any self-trading that occurred on the days covered in this analysis*" (JSR (2015), footnote 28).

[26] Unlike equity markets, cash and futures markets for U.S. Treasuries do not have designated market makers (DMMs). In the context of anonymous electronic trading, voluntary market makers have no particular incentives to provide liquidity continuously. The Chicago Mercantile Exchange uses designated market makers only for new products to promote their acceptance by market participants.

[27] Empirical studies of DMMs in the equity markets show that DMMs tend to stabilize prices and reduce the liquidity premium (Venkataraman and Waisburd (2007), Anand and Venkataraman (2012)).

In the European Union, the revised Market in Financial Instruments Directive (MiFID) introduces requirements for firms pursuing market making strategies. If a firm posts two-way quotes 50 percent of the daily trading hours, it is required to have a market making agreement with the trading venue. The agreement should specify the minimum obligations as well as the list of exceptional circumstances under which market making obligations would be waived (ESMA (2015a)). The draft technical standards also refer explicitly to market making schemes which should provide incentives for liquidity provision under stressed market conditions (ESMA (2015b)).

Trading venues could also consider alternative systems to incentivize liquidity provision. For example, trading venues could require liquidity consumers to pay a fee and offer liquidity providers to receive a rebate (maker/taker fees). [28]

The U.S. authorities could introduce market making requirements for primary dealers, as it is common in many countries (Box 3). The Federal Reserve Bank of New York could introduce requirements that primary dealers maintain a significant continuous presence in secondary markets (quoting obligation and/or active participation). As part of their obligations, primary dealers would have to provide sufficient liquidity by providing two way quotes or any other mechanisms that would be deemed adequate by the authorities. Options that could be explored include minimum limits on bid-ask spreads, minimum amounts of quoted volumes or minimum presence during the usual trading periods.

However, market making requirements should also ensure that market makers are not exposed to significant risks during stress periods. While these obligations would have to be fulfilled most of the time, market participants should be able to avoid having to “catch a falling knife”. Therefore, there could be waivers in place ensuring that they can opt out in period of high stress. These waivers would need to be carefully structured to avoid all-or-nothing ‘triggers’ which might allow designated market makers to opt out en masse, resulting in a sudden and significant decrease in market depth. In some countries such as the UK, those opt out clauses are already in place.[29] However, such opt-out clauses may undermine the effectiveness of any market-making requirements during stress periods.

[28] However, empirical studies on maker/taker fees on equity markets tend to show mixed effects on market quality, especially when markets are fragmented, which would call for more in-depth analysis.

[29] In the UK, PDs are expected to provide two-way quotes between 8:00 AM and 5:00 PM, and those market making obligations are suspended temporarily over the release of economic news or data (AFME (2014)).

Box 3: Market Making Obligations for Primary Dealers

In many countries, the privileges of Primary Dealers are tied to market making obligations on secondary markets. In most European countries and emerging economies, Primary Dealers (PD) have detailed obligations to either provide two-way quotes continuously or to participate actively in secondary markets (Table 1). In Sweden, these obligations are compensated for by commissions from the Debt Management Office for participating in primary and secondary markets (CGFS (2014)). In all countries, safeguards are in place that allow primary dealers to manage their risk by interrupting their liquidity provision and compliance with their obligations is monitored.[30] By contrast, primary dealers in the United States, Japan and Germany have currently no obligations to provide liquidity in secondary markets. Although all three are the most liquid government bond markets in the world, they all have experienced episodes of significant intraday volatility recently. Japan experienced the so-called Value at Risk shock in April 2013, U.S. the Flash Rally on October 15, 2014, and Germany the Bund turbulence in April-May 2015.

Table 1. Primary dealers obligations in secondary markets

Countries with quoting obligations for Primary Dealers		
Belgium	Ireland	Portugal
Denmark	Italy	Spain
France	Malaysia	Sweden
Greece	Mexico	United Kingdom
India	Netherlands	
Countries with active participation obligations for Primary Dealers		
Austria	Canada	Finland
Countries without secondary market obligations for Primary Dealers		
Germany*	Japan	United States

*Germany does not have a Primary Dealership system per se but has rules that apply to the Bund Issues Auction Group.
Sources: AFME European Primary Dealer Handbook, Gemloc (2010)

B. Second line of defense: strengthen market safeguards

A market halt triggered by market safeguards may be beneficial to avoid disorderly trading. The CFTC and the SEC (2010) report in response of the May 6, 2010 Flash Crash in stock and stock-index futures markets noted that a 5-second halt trading "*can be an effective way of providing time for market participants to reassess their strategies, for algorithms to reset their parameters, and for an orderly market to be re-established*" (CFTC-SEC (2010)).

The reasons why existing market safeguards could not prevent large price movements on October 15 have to be examined further. Existing market safeguards could be recalibrated (such as by using a longer window for the "velocity logic" functionality).

[30] In Italy, secondary market performance of PDs is assessed through the Quotation Quality Index which is an indicator based on high-frequency snapshots of the order book for each bond (AFME (2014)).

Changes in market depth could be included as one of the inputs for triggering market safeguards to complement current systems which focus on price variation.

Market safeguards should be introduced in the Treasury cash market. The two main interdealer electronic trading platforms for U.S. Treasury bonds, BrokerTec and eSpeed, do not have any market safeguard mechanism in place.[31] In addition, market safeguards should be harmonized with the Treasury futures market to ensure consistency across asset classes. However, common market safeguards would have to be carefully calibrated to prevent trading halts from being too frequent, as across-the board trading halts could reduce price discovery.

C. Improve the regulatory framework of the Treasury market

"*The Treasury market, the largest and most liquid government securities market in the world, is now arguably the least transparent fixed income market in the U.S.*" (SEC Commissioner Aguilar (2015)).

Structural changes in the market structure suggest that a review of current regulatory requirements applicable to the Treasury market is needed. This includes (i) changes to the regulation, surveillance and supervision of the Treasury market and (ii) changes to the supervision of market participants in the Treasury market.

Regulation, surveillance and supervision of the Treasury market

The regulation, surveillance and supervision of the Treasury market are fragmented. Under the Government Securities Law Act of 1986, the Department of the Treasury can promulgate rules governing transactions in government securities by broker-dealers. The SEC, the Financial Industry Regulatory Authority (FINRA) and federal bank regulators can issue sales practices rules for U.S. Treasuries in secondary markets, in consultation with the Department of the Treasury (Department of the Treasury et al. (1998), JSR (2015)). Surveillance of the Treasury market since 1992 has been conducted by an interagency working group comprised of the U.S. Treasury, the U.S. Federal Reserve Board of Governors, the Federal Reserve Bank of New York, the SEC and the CFTC. In the Treasury futures market, the CFTC and the CME, as a self-regulatory organization, are in charge of regulation and supervision. It is self-evident from this description that strong interagency coordination, eventually under the auspices of the Financial Stability Oversight Council, is warranted.

In the cash markets, trading venues and market participants trading Treasuries are not subject to specific requirements, complicating efforts to analyze and contain systemic risks. The SEC and FINRA regulate and supervise the broker-dealers operating Treasury trading platforms (Alternative Trading Systems (ATSs)). However, ATSs trading exclusively Treasuries are exempted from ATS requirements, as Treasuries are not under the scope of Rule 300(a) of the SEC's Regulation ATS.[32] Moreover, granular FINRA rules such as Rule 2121 Fair Prices and Commission do not apply to Treasury securities. This implies that ATSs

[31] However, ICAP, the owner of the Brokertec platform, is said to have been considering introducing circuit breakers.

[32] Those requirements only apply to ATSs covering equities, municipal securities and corporate debt securities.

are not subject to any requirement regarding market safeguards or liquidity provision schemes.[33] Market participants trading on ATSs are supervised if they are broker-dealers or banks, but other participants and in particular proprietary trading firms are not supervised directly, even if their actions have systemic implications (due to operational risk, market manipulation or inadequate risk management practices for example).

The regulatory perimeter should be expanded. In particular, electronic trading platforms for Treasuries should be subject to specific regulations and participants should be supervised to ensure a level playing field among all market participants and close regulatory loopholes.

A consolidated tape of transactions in the Treasury market would help to enhance market surveillance. While all transactions on equities and corporate bonds are reported to FINRA, there is no reporting requirement for Treasury securities.

Regulation and supervision of HFT firms

Regulation of HFT firms has been lagging behind the dramatic changes in the microstructure of the Treasury market. The rise of electronic proprietary trading firms has sometimes been favored by regulatory changes, but some of those trading firms are not under the regulatory framework in the United States. Concerns related to market integrity, as well as the need for adequate risk management systems and controls to avoid positive feedback loops to occur, call for further regulation of HFT firms.

Currently, only a limited number of proprietary trading firms are directly supervised, leaving room for regulatory arbitrage. In the Treasury futures market, trading firms are supervised by the exchange and the CFTC if they are registered as Futures Commission Merchants (FCMs). If they are not, then it is up to the FCMs they trade with to set up adequate risk controls. If regulators are not prescriptive enough regarding pre-trade risk controls requirements for FCMs, customers could choose the FCM with the least risk controls (Clark and Ranjan (2012)).

The SEC has recently proposed to extend the supervision to proprietary trading firms. Under its proposal, proprietary trading firms would be required to become members of FINRA (SEC (2015)). The JSR also suggests studying specific registration requirements for HFT firms trading Treasuries.

V. CONCLUSION

The flash rally of October 15, 2014 illustrated the fragility of the U.S. Treasury market. The erosion of liquidity following a news release allowed individual trades to have an abnormal market impact, setting the conditions for the flash dynamics. The retail sales data release was widely interpreted as implying that the Federal Reserve might raise policy rates later than expected, leading leveraged funds to cover their short Treasury positions. This was amplified by the longer-term trend of traditional market makers retreating from their customary role of warehousing risk. Without the stabilizing effect of dealers taking large blocks of risk onto their balance sheets, other market participants shied away from executing large orders, for fear of being unable to exit these positions in a quickly moving market. As a

[33] SEC Commissioner Aguilar has recently proposed that specific regulations would be drafted for Treasury trading platforms (Aguilar (2015)).

result, the amount available for purchase or sale at or near the market price fell significantly below normal levels, allowing relatively small orders to move the price quickly through successive price levels. Market participants remained largely active at high frequencies throughout the episode and made numerous small trades at rapidly changing prices, driving total trading volumes to record levels. As prices never ‘gapped’, i.e. prices moved through consecutive levels without skipping over one or more price levels, market safeguards were not triggered and did not manage to mitigate the shock.

Changes in the structure and functioning of Treasury markets have affected the provision of liquidity. Technological advances have made the automation of trading strategies widespread in the U.S. Treasury market, giving rise to a new breed of market makers: HFT firms. These new actors rely on small inventories to make markets and adjust their holdings rapidly in times of stress. At the same time, traditional market makers have curbed their liquidity provision and adopted automated trading strategies as well. These changes are driven by a combination of factors including competition, changes in business models since the onset of the Global Financial Crisis (GFC), and possibly new regulations.

Measures to improve the resiliency of the U.S. Treasury market are warranted. The current frameworks for the surveillance, oversight, regulation and supervision of the Treasury markets and market participants have not kept pace with changes to market structure over recent years. Fragmented supervision, regulatory loopholes and significant data gaps prevent authorities from having a complete view of the U.S. Treasury market. Given its importance, it is crucial to ensure that market liquidity remains available, especially during volatile times. The provision of liquidity could be incentivized or mandated in the case of primary dealers. Designated Market Makers could also be introduced. Market safeguards should be improved, including by taking account of market depth directly. Adequate regulatory and supervisory oversight is key, along with the design and implementation of market safeguards to prevent such event from occurring again.

APPENDIX 1: MARKET SAFEGUARDS ON THE CHICAGO MERCANTILE EXCHANGE

I. The Stop logic and Velocity functionalities

The CME uses two main market safeguards: the Stop Logic and the Velocity Logic functionalities. The Stop-Logic is a pre-trade risk control while the Velocity Logic is a post-trade risk control. Stop Logic is designed to limit the price impact of the triggering of a single stop order: if the execution of a stop order leads to a large price change, trading is halted for a few seconds. Velocity Logic is designed to prevent excessive price change within a given period of time: if one-second (absolute) price changes are above a threshold, trading is halted for a few seconds.

Stop Logic

Stop Logic detects potential market movements caused by the execution of stop orders. If the execution of a stop order would lead to price moves above a specified threshold, trading is halted. If liquidity is low in the order book (i.e. there are low quantities available at different price levels), then the execution of a large stop order will deplete market depth, resulting in a large price swing (see the numerical example below). This safeguard only applies to stop orders and not to other types of orders (i.e. market orders or traditional limit orders).

Numerical Example

- Suppose the threshold for the Stop Logic is 6 points.
- The security is currently traded at the price above 1070, but a seller expects the price to decline and places a Stop sell order for 250 contracts at the triggering price of 1070.
- Suppose that a trade is executed at the price of 1070. This triggers the stop order to sell 250 contracts at the best price available.
- Suppose the state of the bid-side of the order book (orders offered to sellers) is as shown in the table below. Given the low liquidity available, this order would be executed down to 7 price levels of the order book (to fill the order of 250 contracts). This would bring down prices to 1063. This would be more than 6 points below the previous price.
- Because the new price level would be more than 6 points below the current price, the Stop Logic safeguard would halt trading.
- After a few seconds (typically 5 seconds), trading resumes.

Conditions

Stop Logic Value	**6** points
Stop sell order	Size of 250 contracts at the triggering price of 1070

State of Order book when the Stop sell order is triggered

Price	Quantities offered to sellers (Buy limit orders)	Cumulated quantities
1070	10	10
1069	50	60
1068	40	100
1067	25	125
1066	75	200
1065	20	220
1064	10	230
1063	40	270
1062	20	290

Expected impact	**-7** points ⇨ Stop Logic will be triggered

<u>Velocity Logic</u>

Velocity Logic is designed to detect market movements in either direction larger than a predefined value within a certain time, (typically 1.5 point over a one-second window for U.S. Treasury futures). When price moves are larger than the threshold, trading is halted.

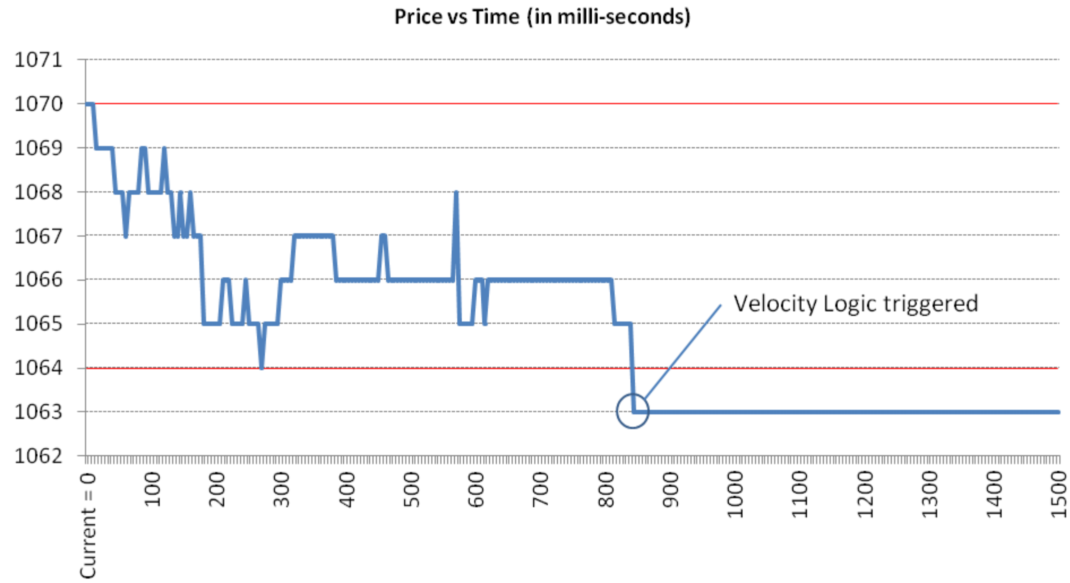
Numerical Example

- Suppose the Velocity Logic threshold is set to 6 points within a second.
- Suppose the security is currently traded at the price of 1070, but large seller orders (either market orders or limit orders) are placed, and as a result, the market moves downwards for 7 points in 830 milliseconds.
- Then, Velocity Logic is triggered and the trading is halted for a few second.
- At the end of the trading halt, trading resumes.

Conditions

Velocity Logic Value	**6** points within one second

Figure 1: Price



II. The design of market safeguards and the events of October 15, 2014

Market safeguards employed by the CME, such as Stop Logic and Velocity Logic, were not triggered because despite the high volatility, prices moved up in small increments over a relatively long period of time. This is contrast with past events where market safeguards were triggered (Box 1).

If the velocity logic safeguard had used a longer time window, it would have been triggered. For example the price change of 10-year UST futures between 9:32 and 9:40 on October 15, was higher than the threshold value of the velocity logic on U.S. Treasury futures (1.5 point). Therefore the use of a longer time window might be a way to improve the calibration of market safeguards.

Including the current level of depth in the order book as a trigger for market safeguards could also have mitigated the price action on October 15. In the current setting, market depth is only used indirectly: when market depth is low then there is a higher probability that price changes after execution will be high and that stop loss order would lead to large price moves. However on October 15, the execution of stop orders did not trigger the stop logic function either because there were no stop orders or because there were at prices closed to market prices. If abrupt changes in market depth, such as the 75 percent decline which occurred between 8:50 and 9:30, would be included as trigger for market safeguards, they could mitigate ex ante the risk of flash dynamics to occur. For example, if the velocity logic would be applied to market depth, rather than price, a trading halt would occur if the decline in market depth over a given time frame is larger than a given value. Of course the calibration would need to be adequately assessed: for example, ahead of news releases, market depth typically vanishes and market safeguards should not be triggered in those instances.

Box 1. Circuit breakers on U.S. Treasury futures
Even though the market safeguards were not triggered on October 15, they have been triggered previously (Table 1).

Table 1: Recent events in which the circuit breakers were triggered

Date	Futures	Event/news release
7 June 2013	5Y, 30Y, eMini	Non farm payroll
2 August 2013	5Y	Non farm payroll
8 November 2013	5Y, 30Y	Non farm payroll
10 January 2014	5Y	Non farm payroll
4 April 2014	5Y	Non farm payroll
5 December 2014	30Y	Non farm payroll

There were also some events in which the price movement was large in hindsight but the safeguards were not triggered. For example, the 10-year Treasury futures price declined about 0.4 percent within one minute interval around 10:05 am on 29 February 2012. On 23 December 2013, the 30-year Treasury futures price ascended about 4.2 per cent over one minute interval around 2:38 am. The market safeguards were not triggered in either of these events. Just as in the October 15 event, the price movement was smooth when looked at a very small intervals (25-millisecond) but very large cumulatively.

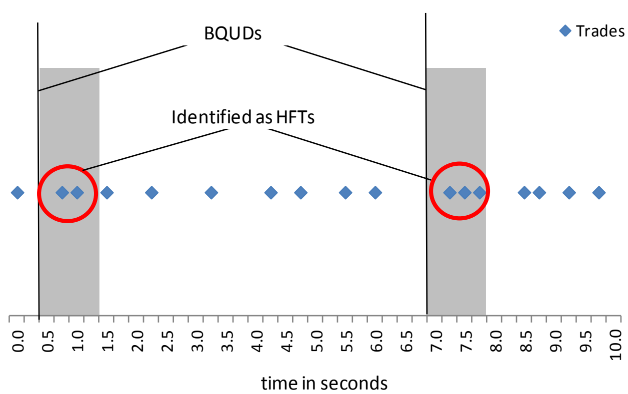
APPENDIX 2: ESTIMATION OF REACTIVE TRADES

In this appendix, we explain the method to estimate the volume of Reactive Trades (RTs) as a proxy for HFT activity. We define a RT as a trade that is placed in reaction to an update of the best quote in the limit order book. The general idea is that when a trade occurs very quickly after an update of the order book, there is a high probability that this trade comes from an HFT firm. For example, if we assume that a manual trader sends market orders every second, then if a trade occurs less than 10 millisecond after an order book update, there is a high probability that it comes from an HFT firm.

I. Reactive Trades

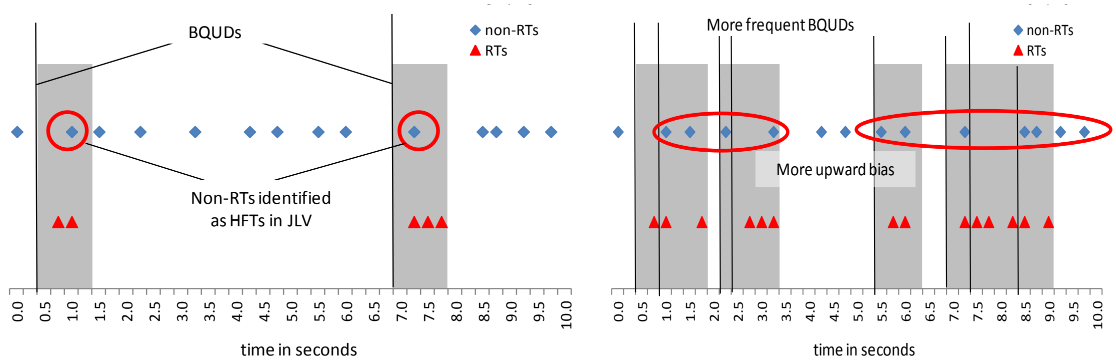
The aim of the analysis is to infer the level of algorithmic and high frequency trading (HFT) in the US Treasury futures market during the flash rally on October 15. Commercial data on the Treasury futures market do not include an identifier to distinguish HFT trades from non-HFT trades. Jiang, Lo and Valente (2014, JLV hereafter) proposed a procedure to identify HFT based on the speed of order placement. They classify trades (market orders) as HFT trades when they occur within a second of a change in the best quote on either side of the market (Best Quote Update or BQUD). This is based on the reasoning that manual traders cannot react to market events such fast (Figure 1).

Figure 1. Illustration of HFT and non-HFT Trades in JLV



In line with JLV, we consider a Reactive Trade (RT), or a trade (market order) that is placed in reaction to a BQUD, as a proxy for HFT. However, during volatile periods, the number of BQUD increases which could lead to an upward bias in the estimation of HFT activity as non-RTs can be wrongly estimated as RTs if they randomly occur just after a BQUD. The more BQUDs occur, the higher is the probability non-RT trades are by chance executed within one second of BQUD (blue diamonds in Figure 2).

Figure 2. Illustration of Non-RTs Identified as HFTs in JLV



Additionally, using one second as a threshold to distinguish automated trading from manual trading is *ad hoc* and might be too slow for measuring HFT activity which typically occurs over milliseconds. In order to address these shortcomings in the JLV method and estimate volume traded by RTs, we model the occurrence of RTs and non-RTs as in the following section.

II. Model

The next sections describe the model in detail. In our model, four events can occur: a non-simultaneous best quote update (BQUD), a simultaneous BQUD (i.e. occurring with a trade), a trade occurring in reaction to the BQUD (Reactive Trade) or a non-Reactive Trade.

a) Reactive Trades, non Reactive Trades and Best Quote Updates

We analyze trading activity on a day starting at time $t = 0$ and ending at $t = T$.

We focus on four types of events that can occur during the trading session:

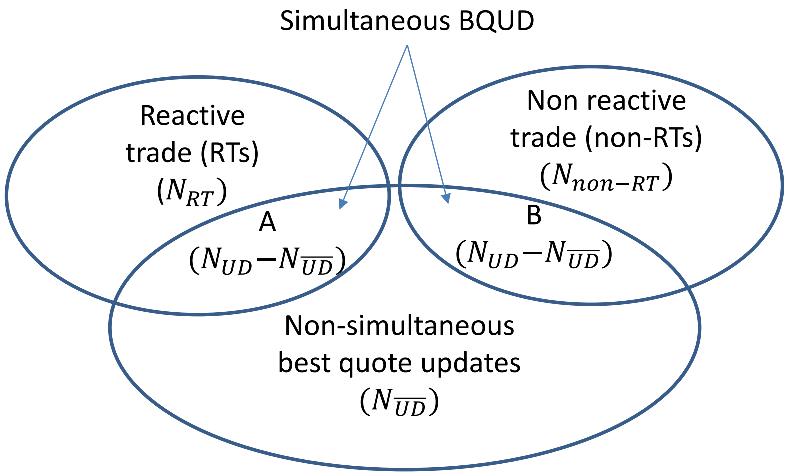
i. a reactive trade (RT),
ii. a non-reactive trade (non-RT),
iii. a non-simultaneous best quote update (BQUD), and
iv. a simultaneous BQUD.

Let $N_{RT}(t)$ and $N_{non-RT}(t)$ denote the number of RTs and non-RTs that occur by time t. We cannot directly observe $N_{RT}(t)$ or $N_{non-RT}(t)$. We only observe the sum of these two numbers, $N_{Trade}(t) \coloneqq N_{RT}(t) + N_{non-RT}(t)$.

Let $N_{UD}(t)$ denotes the number of BQUDs by time t. Then, let $\tau^{UD}(t) := \sup(u \geq 0; N_{UD}(u) < N_{UD}(t))$ be the time of the latest BQUD up to time t.

Since RTs and non-RTs can occur at the same time of a BQUD, we need to disentangle simultaneous BQUDs, or BQUDs which occur simultaneously with trades (which corresponds to areas A and B in Figure 3), and non-simultaneous BQUDs, or BQUDs which do not occur simultaneously with trades. $N_{\overline{UD}}(t)$ is the number of non-simultaneous BQUDs by time t. By definition, RTs, non-RTs and non-simultaneous BQUDs are mutually exclusive. The difference $N_{UD}(t) - N_{\overline{UD}}(t)$ indicates the number of simultaneous BQUDs up to time t.

Figure 3. Possible Events



b) Probability of non-Reactive Trades and non-simultaneous Best Quote Updates

For simplicity, we assume that non-RTs and non-simultaneous BQUDs are completely exogenous and do not depend on past information. Under such assumptions, for very small $\Delta > 0$, probabilities at time *t* of occurrence of non-RTs are given by :

$$P(N_{non-RT}(t+\Delta) > N_{non-RT}(t)) = \lambda_{non-RT}(t)\Delta \qquad (1)$$

Similarly, probabilities of non-simultaneous BQUDs between time t and $t+\Delta$ can be expressed as:

$$P(N_{\overline{UD}}(t+\Delta) > N_{\overline{UD}}(t)) = \lambda_{\overline{UD}}(t)\Delta \qquad (2)$$

We assume that the frequency of occurrences of RTs and non-simultaneous BQUDs (i.e. the intensity functions λ_{non-RT} and $\lambda_{\overline{UD}}$) is a deterministic function of time.

c) Probability of Reactive Trades and simultaneous Best Quote Updates

On the contrary, RTs and simultaneous BQUDs are assumed to occur in reaction to other past events reflected in $\tau^{UD}(t)$. Specifically, for very small $\Delta > 0$, we assume that the probability of occurrence of RTs between time t and $t+\Delta$ can be expressed as:

$$P(N_{RT}(t+\Delta) > N_{RT}(t) | \tau^{UD}(t)) = \lambda_{RT}(t, \tau^{UD}(t))\Delta \qquad (3)$$

The intensity λ_{RT} is a function of current time and time of the latest BQUD: Reactive Trades react to past information (specifically BQUD).The implicit assumption though is that the probability of RTs occurring over small time intervals depends on past information only through $\tau^{UD}(t)$.[34]

With regard to the occurrence of simultaneous BQUDs, we assume a function q of time *t*, that indicates the probability of having a BQUD at time *t* conditional on having a trade a time *t*. That is:

$$P(N_{UD}(t) > N_{UD}(t_-) | N_{Trade}(t) > N_{Trade}(t_-)) = q(t) \qquad (4)$$

[34] The probabilities in (1) through (3) are not explicitly conditioned on information at *t*, on the basis that the past information other than $\tau^{UD}(t)$ gives no additional information regarding future occurrence of events.

We assume this probability to be independent of all other information up to *t*.

d) Probability of no event occurring

We assume the additivity of the intensities in (1) through (3).[35] Then, the probability at time *t* of no event occurring between time t and s (no RT, no non-RT and no BQUD) is given by:

$$P(N_{Trade}(s) = N_{Trade}(t), N_{UD}(s) = N_{UD}(t) | \tau^{UD}(t))$$
$$= \exp\left(-\int_t^s \lambda_{RT}(u, \tau^{UD}(t))\, du - \int_t^s \lambda_{non-RT}(u)\, du - \int_t^s \lambda_{\overline{UD}}(u)\, du\right), \text{ for } \quad s > t \quad (5)$$

Let $\lambda(t, \tau) \coloneqq \lambda_{RT}(t, \tau) + \lambda_{non-RT}(t) + \lambda_{\overline{UD}}(t)$ denote the sum of intensities, and let $\delta(t) := \inf(h \geq 0; N_{Trade}(t+h) + N_{UD}(t+h) > N_{Trade}(t) + N_{UD}(t))$ be the time elapsed from *t* until the next event (either a trade or a BQUD after *t*). Then, equation (5) can be rewritten as:

$$P(t + \delta(t) > s | \tau^{UD}(t)) = \exp(-\int_t^s \lambda(u, \tau^{UD}(t))\, du) \qquad (6)$$

From this, we can derive the time *t*-density function $f_{\delta,t}$ of $\delta(t)$:

$$f_{\delta,t}(h | \tau^{UD}(t)) = \lambda(t + h, \tau^{UD}(t)) \exp(-\int_t^{t+h} \lambda(u, \tau^{UD}(t))\, du) \qquad (7)$$

The density of some event occurring in h seconds after current time *t* therefore depends on past information ($\tau^{UD}(t)$, or the latest BQUD up to current time *t*) .

e) Specification of the intensities

We divide the entire observation period in intervals from 0 to T: $0 = t_0 < t_1, \ldots, < t_n = T$. We assume that λ_{non-RT} and $\lambda_{\overline{UD}}$ remain constant in each interval $(t_{i-1}, t_i]$ for $i = 1, \ldots, n$:

$$\lambda_{non-RT}(t) = \lambda^i_{non-RT}, \text{ for } \quad t \in (t_{i-1}, t_i] \qquad (8)$$
$$\lambda_{\overline{UD}}(t) = \lambda^i_{\overline{UD}} \quad, \text{ for } \quad t \in (t_{i-1}, t_i] \qquad (9)$$

In other words, the arrival frequency of non-RTs and non-simultaneous BQUDs is constant within each interval but can change between time intervals.

We also assume the following functional form for λ_{RT}:

$$\lambda_{RT}(t, \tau) = \lambda^i_{RT}\, g(t - \tau) \quad \text{for} \quad t \in (t_{i-1}, t_i] \qquad (10)$$

where g is a continuous function defined on $[0, +\infty)$ such that $g(0) = 1, g(h) > 0$ for any $h > 0$ and $g(h) \to 0$ as $h \to +\infty$. Therefore, the intensity of reactive trades is a decreasing function of the time difference between t and τ: the longer the interval between an event and a trade, the lower the frequency of RTs.

We assume, for the sake of tractability, the following functional form for g in (10):

$$g(h) = \exp(-h^2/2\sigma^2) \qquad (11)$$

Finally, we also assume that the probability of simultaneous BQUDs q stays constant in each interval $(t_{i-1}, t_i]$ for $i = 1, \ldots, n$:

$$q(t) = q^i \quad, \text{ for } \quad t \in (t_{i-1}, t_i] \qquad (13)$$

[35] This is basically to assume 'instantaneous independence' of processes, or to assume the independence of (1), (2) and (3) given the information up to *t*.

f) Volume traded for each trade

HFT firms tend to trade in smaller quantities than non-HFT firms. Therefore, Reactive strategies tend to trade in smaller quantities than non-Reactive strategies: this can be verified by comparing the histogram of numbers of contracts traded quickly after order book updates and trades occurring well after order book updates. For simplicity, we assume that the number of contracts traded in each RT, denoted by V_{RT}, and each non-RT, denoted by V_{non-RT}, respectively follow an exponential distribution with different parameters $\eta_{RT}$and η_{non-RT}. Formally, assuming a trade occurs at time t, we have:

$$V_{RT}(t)|\ N_{RT}(t) > N_{RT}(t_{-}) \quad \sim \quad Exponential\ (\eta_{RT}) \quad (0)$$

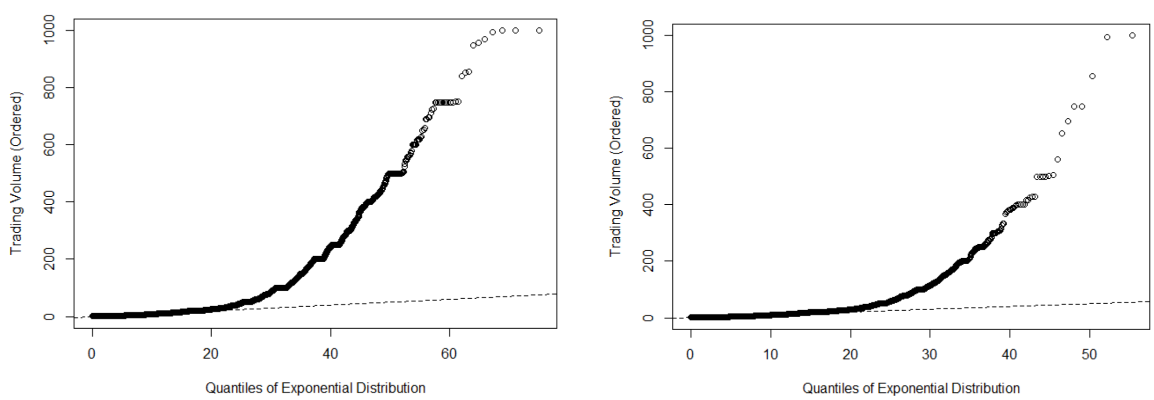
and

$$V_{non-RT}(t)|\ N_{non-RT}(t) > N_{non-RT}(t_{-}) \quad \sim \quad Exponential\ (\eta_{non-RT}) \quad (14)$$

The choice of exponential distributions is justified by looking at the Quantile-Quantile plot of the volume traded on October 15 against the exponential distribution: left panel is for all trades, and the right panel is for trades that happen within 100 milliseconds of BQUDs (Figure 4). For trades below 20 contracts (95 percent of all trades), the exponential distribution fits the data.

Figure 4. Q-Q Plot of the Volume Traded on October, 15 against Exponential Distribution

All Trades (left panel) | Trades within 100ms of BQUDs (right panel)



III. Estimation of Parameters

a) Estimation of frequency parameters

The model has a set of parameters $\Theta = \{\sigma, \left(\lambda_{RT}^{i}, \lambda_{non-RT}^{i}, \lambda_{\overline{UD}}^{i}, q^{i}\right)_{i=1,\dots,n}\}$ regarding the frequency of events, and η_{RT} and η_{non-RT} regarding the trading volume
To estimate the frequency parameters Θ, we observe for each event (trade and BQUD) the minimum time elapsed after the previous event (BQUD or the previous trade).
Specifically, suppose that we observe events (trades and BQUDs) on $0 \leq t_1, t_2, \dots, t_J \leq T$.
Let $h_1 = t_1$, and $h_j = t_j - t_{j-1}$ for $j = 2, \dots, J$.

Let $X_j = I\{N_{Trade}(t_j) > N_{Trade}(t_{j-})\} = 1 - I\{N_{\overline{UD}}(t_j) > N_{\overline{UD}}(t_{j-})\}$ be a variable that indicates that a trade occurs at t_j. Given that we observe an event at t_j, it is either a non-simulatenous quote update $\{N_{\overline{UD}}(t_j) > N_{\overline{UD}}(t_{j-})\}$ or a trade $\{N_{Trade}(t_j) > N_{Trade}(t_{j-})\}$ hence the probability of observing a trade is equal to 1 minus the probability of observing a non simultaneous order book update.
Finally, let $Y_j = I\{N_{UD}(t_j) > N_{UD}(t_{j-})\}$ be a variable that indicates that a BQUD occurs at t_j for *j = 1,…,J*.
Then, we are interested in the likelihood of the observation $\{h_j, X_j, Y_j, \tau^{UD}(t_j)\}_{j=1,\dots,J}$.
Note that $\tau^{UD}(t_j)$ is determined when X_j, Y_j and $\tau^{UD}(t_{j-1})$ are known.
A priori, $P_{tj}(X_j = 1) = \left\{\lambda_{RT}\left(t_j, \tau^{UD}(t_j)\right) + \lambda_{non-RT}(t_j)\right\} / \lambda(t_j, \tau^{UD}(t_j))$,
$P(Y_j = 1 | X_j = 1) = q(t_j)$ and $P(Y_j = 1 | X_j = 0) = 1$, where $P_{t_j}(\cdot) \coloneqq P(\cdot \,| N_{Trade}(t_j) > N_{Trade}(t_{j-})\ or\ N_{UD}(t_j) > N_{UD}(t_{j-}))$ is a probability conditional on occurrence of a trade or a BQUD at t_j. From equation (7), the density of h_j conditional on the *(j-1)* th observation is given by $f_{\delta, t_{j-1}}(h_j | \tau^{UD}(t_{j-1}))$. Thus, the log-likelihood l of the observations is given by:

$$l\left(\{h_j, X_j, Y_j, \tau^{UD}(t_j)\}_{j=1,\dots,J} \middle| \Theta\right) = \underbrace{\log f_{\delta,0}(h_1 | \tau^{UD}(0)) + \sum_{j=2}^{J} \log f_{\delta, t_{j-1}}\left(h_j \middle| \tau^{UD}(t_{j-1})\right)}_{Time\ observed\ between\ two\ events} + \underbrace{\sum_{j=1}^{J} (\log P_{tj}(X_j) + \log P_{tj}(Y_j | X_j))}_{Types\ of\ events\ observed} \qquad (15)$$

Now we can estimate the parameters Θ of equation (15) by maximum likelihood method (ML).

b) Specification of time intervals

As for the division of the observation period at $0 = t_0 < t_1, \dots, < t_n = T$, if n is too small then the model cannot track the time-varying intensities, whereas if *n* is too large, then the model over-fit the data: estimated parameters pick up noise rather than the underlying structure of the data. To balance between the two while maintaining tractability of calculation, we estimate parameters over one-minute intervals and smooth the estimated parameters using a Kalman filter.[36] Observation error matrices at each *i= 1,…,n* are set at the inverse of the estimated Fisher information matrix.

c) Validation of the estimation method

To check the validity of using the one minute intervals, we simulate sample data from the model over a one-minute period and test the abovementioned estimation method. Reflecting the estimated values for October 15, parameters are set at:
$\sigma = 0.02,\ \ \lambda_{RT} = 300,\ \ \lambda_{non-RT} = 60,\ \ \ \lambda_{\overline{UD}} = 30,\ \ \ q = 0.3$.
We generate 100 sets of RTs and non RTs data and then estimate parameters for each data set. Table 1 shows the summary of estimated parameters, indicating that the estimation method performs well, at least when the data are generated from the model described.

[36] We performed some robustness checks using 5-minutes intervals which yielded similar results.

Table 1: Means and Standard Deviations of estimated parameters (simulation # = 100)

Parameters	True Value	Mean of Estimated Parameters	Standard Deviation of Estimated Parameters
σ	0.02	0.02033	0.00091
λ_{RT}	300	296.0	8.8
λ_{non-RT}	60	59.29	8.78
$\lambda_{\overline{UD}}$	30	29.91	0.70

c) Estimation of Reactive Trades

We estimate the parameters η_{RT} and η_{non-RT} by maximum likelihood.

Let $\pi(t) = \lambda_{RT}(t, \tau^{UD}(t)) / (\lambda_{RT}(t, \tau^{UD}(t)) + \lambda_{non-RT}(t))$ be the probability that the observed trade is a RT, we can derive the density function $f_{V(t)}$ of the volume $V(t)$ traded in each trade as:

$$f_{V(t)}(v) = \pi(t)\eta_{RT}\exp(-\eta_{RT}v) + (1-\pi(t))\eta_{non-RT}\exp(-\eta_{non-RT}v) \qquad (16)$$

Suppose a trade occurs at time t. We can use $\pi(t) = \lambda_{RT}(t, \tau^{UD}(t)) / (\lambda_{RT}(t, \tau^{UD}(t)) + \lambda_{non-RT}(t))$ as the prior probability that the trade is a RT. By also observing the volume traded $V(t)$, we can obtain the posterior probability $\pi_{post}(t)$ as:

$$\pi_{post}(t) = \frac{\pi(t)\eta_{RT}\exp(-\eta_{RT}V(t))}{\pi(t)\eta_{RT}\exp(-\eta_{RT}V(t)) + (1-\pi(t))\eta_{non-RT}\exp(-\eta_{non-RT}V(t))} \qquad (17)$$

We estimate the aggregate volume $AV_{RT}(t,s)$ traded by RT and the aggregate volume $AV_{non-RT}(t,s)$ traded by non-RT between t and s by:

$$AV_{RT}(t,s) = \sum_{h\in(t,s],\, N_{trade}(h)>N_{trade}(h_-)} \pi_{post}(h)V(h) \qquad (18)$$

and

$$AV_{non-RT}(t,s) = \sum_{h\in(t,s],\, N_{trade}(h)>N_{trade}(h_-)} (1-\pi_{post}(h))V(h) \qquad (19)$$

Using those estimates we compute the share of RTs activity as a proxy for some HFT strategies.

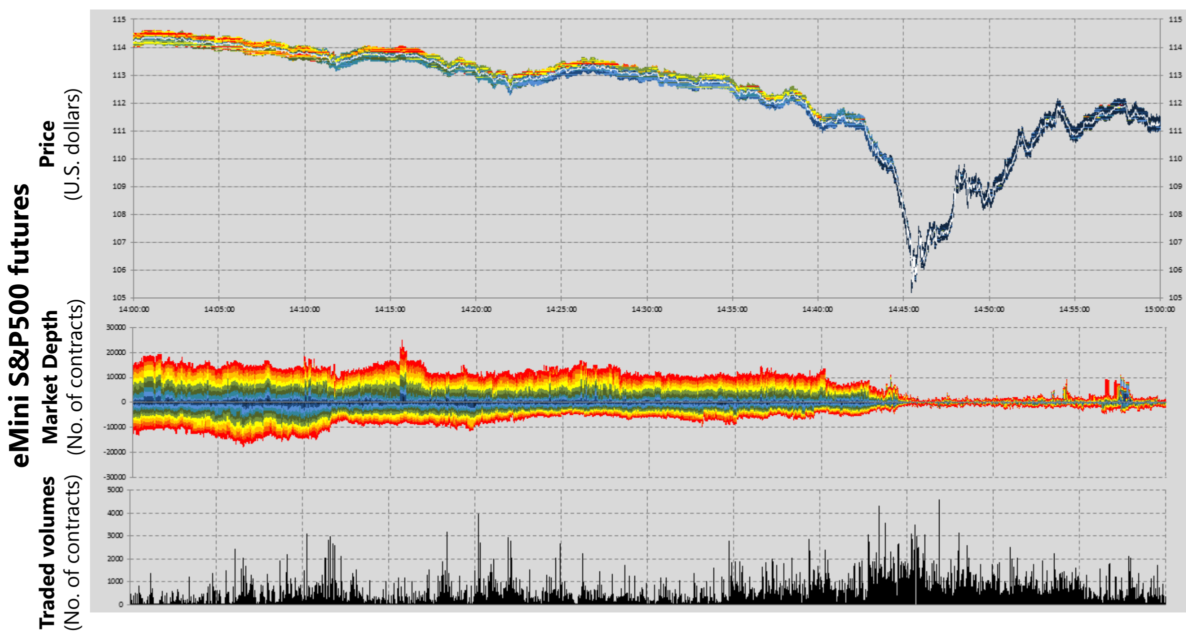
APPENDIX 3: THE MAY 6, 2010 FLASH CRASH

On May 6, 2010, U.S. equities and futures on equity indices experienced a flash crash. The event started on eMini futures (futures on the S&P500), where significant selling pressure reduced liquidity, leading to significant price changes (see SEC-CFTC (2010) and Kirilenko et al. (2014) for further details).

As shown in Figure 1, the equity flash crash bears some resemblance with the Treasury flash rally. Liquidity dried up rapidly among trading pressure (selling pressure for the equity flash crash, buying pressure for the Treasury) amid record high volumes. As market depth was depleted, each single trade had a large price impact, resulting in further volatility and leading to the 'hot potato' effect. During the equity flash crash, circuit breakers got triggered in the futures markets: the Stop Logic functionality lead to a 5-second pause as the execution of stop loss orders would have led to price moves larger than the Stop Logic threshold.

The SEC and the CFTC acknowledged in their joint report that CME's Stop Logic "*can be an effective way of providing time for market participants to reassess their strategies, for algorithms to reset their parameters, and for an orderly market to be re-established*" (SEC-CFTC (2010). During the Treasury flash rally, circuit breakers were not triggered.

Figure 1. The May 6, 2010 Flash Crash



Source: CME DataMine; and IMF staff.

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