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STOCK PRICE CRASHES:
ROLE OF SLOW-MOVING CAPITAL

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ABSTRACT

We study the role of various trader types in providing liquidity in spot and futures markets based on complete order-book and transactions data as well as cross-market trader identifiers from the National Stock Exchange of India for a single large stock. During normal times, short-term traders who carry little inventory overnight are the primary intermediaries in both spot and futures markets, and changes in futures prices Granger-cause changes in spot prices. However, during two days of fast crashes, Granger-causality ran both ways. Both crashes were due to large-scale selling by foreign institutional investors in the spot market. Buying by short-term traders and cross-market traders was insufficient to stop the crashes. Mutual funds, patient traders with better trade-execution quality who were initially slow to move in, eventually bought sufficient quantities leading to price recovery in both markets. Our findings suggest that market stability requires the presence of well-capitalized standby liquidity providers.

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A liquid and stable stock market plays a critical role in the economy. It channels savings into long-term illiquid investments while at the same time providing liquidity to investors, thereby promoting economic growth (see Levine (2005)). The "Flash Crash" of May 6, 2010, focused the attention of exchanges and regulators on the need to better understand the forces that affect market liquidity and stability. According to CFTC and SEC (2010) report, there was a large institutional sell order (more than USD 4 billion) for E-mini S&P 500 futures that was quickly executed, resulting in the price crashing by more than 9% and bouncing back within 30 minutes. This has led to an ongoing debate regarding the role of high-frequency traders (HFTs) in precipitating crashes.[1] SEC (2010) defines HFTs as algorithmic traders having two characteristics: (i) superior speed relative to other market participants and (ii) little intraday and end-of-day inventory positions, indicating their limited inventory capacity. We contribute to the debate by focusing on the role the HFTs' second attribute plays in crashes.

We show that traders who carry little end-of-day inventory (short-term traders [STTs]) are the primary providers of liquidity during most times, with no distinction between the spot and the futures markets. Cross-market arbitrageurs are also largely traders who carry little inventory (i.e., they are a subset of STTs) and thus, they lack the capacity to prevent crashes. When the demand for liquidity is unusually large, STTs' inventory capacity is stretched, and prices crash until mutual funds (MFs) and other standby liquidity providers are able to step in to provide liquidity, thereby helping price recovery. MFs, however, have a natural advantage in making a market for stocks they hold when the rewards are adequate (i.e., when price concessions are large enough – they moved in only after prices dropped

[1] Easley, de Prado, and O'Hara (2012) show that order-flow toxicity increased in the hours before the Flash Crash, making liquidity provision costly and eventually leading to the withdrawal of many liquidity providers – most of whom were HFTs – from the market. In contrast, Kirilenko, Kyle, Samadi, and Tuzun (2017) show that HFTs were important market participants (jointly responsible for 34% of the trading volume in E-mini S&P 500 futures on the days surrounding the Flash Crash) and that their behavior did not change during the Flash Crash. Subsequently, Menkveld and Yueshen (2018) found that cross-market arbitrage typically conducted by HFTs broke down prior to the Flash Crash, consistent with arguments in Easley, de Prado, and O'Hara (2012).

sufficiently).[2] Our findings highlight the slow-moving feature of standby market-making capital that enables recovery from crashes in the stock and futures markets. Our results are consistent with Mitchell, Pedersen, and Pulvino (2007), who made a related observation based on data from the convertible debt market.

We use a unique database of orders and transactions data for the period April – June 2006 for a large firm in the NIFTY-50 and SENSEX indexes traded on the National Stock Exchange of India (NSE).[3] Based on the number of trades, the NSE was the third-largest stock exchange after NYSE and NASDAQ in the world in 2006. Even though we use data for three months in 2006 for just one stock from the NSE, we believe that our main conclusions carry over to the current U.S. stock market and several other markets around the world.

Our data have the following advantages. First, the data have a unique identifier for each broker-trader combination across spot and futures markets, which allows us to calculate the evolution of individual traders' inventory over time.[4] Second, the data have the legal classification (Mutual Fund [MF], Foreign Institutional Investor [FII], etc.) for each trader in addition to the unique individual trader identity. Therefore, we are able to identify the types of legal entities who are standby liquidity providers. Third, we are able to track individual traders who trade across spot and futures markets, which allows us to examine cross-market activity and spillover effects.

In this study, we go beyond legal classification of traders and identify short-term and long-term liquidity providers directly based on their trading behavior. Short-term liquidity providers (STTs) tolerate deviations from their desired inventory positions only for short

[2]Another potential reason for the slow-moving nature of MFs' intermediation capital could be the following. A sharp drop in the price of a stock draws the attention of MFs who have to evaluate whether this drop is due to lack of liquidity or adverse information. And this evaluation may take time, slowing the deployment of market-making capital.

[3]NSE became the largest stock exchange in India in terms of volume traded, overtaking the Bombay Stock Exchange (BSE) at the end of 1995. The NSE is organized as a limit order book market, which has become the dominant market design.

[4]We note that this firm's stock is traded in both the spot and the single-stock futures markets, with the trading volume in the futures market being almost five times larger than the trading volume in the spot market.

periods of time. Long-term liquidity providers (LTTs) can tolerate persistent deviations from their target inventory positions. Some legal entities are natural liquidity providers and demanders: MFs can tolerate deviations from their desired holdings if prices become attractive; FIIs have a global view on the market, and thus their behavior might be affected by the shocks originated outside the Indian market. Therefore, we keep them as separate trader categories.

We find that STTs, who carry relatively small amounts of intraday inventory relative to their trading volume and carry little inventory overnight (less than 10% of their daily trading volume), are present in at least one side of the transaction for 85% (89%) of the daily transactions in the spot (futures) market. Moreover, 37% (45%) of the daily trading volume in the spot (futures) market occurs among STTs themselves. Overall, STTs act as main intermediaries in both spot and futures markets. Though each individual trader belonging to the STT category has a limited inventory capacity, STTs as a group are able to provide sufficient liquidity to both spot and futures markets. They use trading among themselves as an important inventory-management tool.

During our sample period, high-frequency trading (and any algorithmic trading in general) was not allowed at the NSE, and thus any order submission, modification, and/or cancellation required a manual entry. Our data therefore provide us with a unique laboratory to isolate the effect of the second characteristic of HFTs in fast crashes.

There were two fast crashes and recoveries in both spot and futures markets together with stock market indices such as NIFTY and SENSEX.[5] The first (second) fast crash was

[5]Analysts speculated that the reason for this drop was that the U.S. CPI number, released a day before the first crash, was above expectations, indicating rising U.S. interest rates. This, coupled with weaknesses observed in the London Metal Exchange, has led to losses in emerging markets like India, Mexico, and Brazil. As a result, on May 18, 2006, the SENSEX (Indian stock market index) registered a fall of 826 points (6.76%) to close at 11,391, followed heavy selling by foreign institutions and weakness in global markets. This market meltdown was followed by a drop in SENSEX on May 19, 2006, by 452 points and the biggest intraday fall in the history of Indian stock market on May 22, 2006, when SENSEX dropped by 1,111 points, triggering a market-wide circuit breaker. Market crashes on May 19, 2006, and May 22, 2006, are also identified as fast crash periods for the anonymous stock under consideration.

characterized by a drop in the spot market mid-quote by 7.9% (10.2%) within 30 minutes, followed by sharp recovery of more than 60% within the 30 minutes after the trough of the crash. The futures market experienced contemporaneous price crashes and recoveries comparable to the spot market.

The unusually large liquidity shocks in both crashes were due to large selling pressure coming from FIIs (as defined by the NSE) in the spot market that spilled over to the futures market. We find that 50% of STTs who were active on the crash days withdrew from the market during the drawdown period, and 60% of those STTs who remained active hit their inventory constraints on the crash days. Therefore, market recovery required better-capitalized standby liquidity providers to step in.

In our sample, we find that MFs were patient traders, buying when prices went down and selling when prices went up. Some MFs entered the market and bought only during the crash days. Moreover, net aggressive buying by MFs Granger-caused a rise in spot prices during the crash days; however, there was no observed causality during non-crash days. Further, spot returns did not Granger-cause net aggressive buying by MFs during crash and non-crash days. This is consistent with buying by MFs helping price recovery, but price recovery did not cause MFs to buy. Interestingly, spot and futures returns Granger-caused each other during crash days, whereas causality ran from futures to spot market during non-crash days. This is consistent with both crashes originating in the spot market and spilling over into the futures market (Note that the crash-day causality averages the effects during market drawdown and other periods in the day. The market drawdown period is too short to estimate causality.)

To summarize, we provide a comprehensive analysis of the roles of STTs, cross-market traders, and slow-moving standby liquidity providers during price crashes and recoveries. The rest of the paper is organized as follows. Section I relates our work to the literature. Section II describes the data. Section III introduces the methodology we use to identify STTs and LTTs. Section IV characterizes intraday liquidity provision by STTs and long-term liquidity provision by institutional investors during the two fast crashes in our sample and describes the stabilizing role of the slow-moving capital. We conclude in Section V.

I. Related literature

We contribute to two different streams of literature: liquidity provision in open limit order book markets and market fragility. The literature on liquidity provision is vast and covers markets of different financial instruments (equities, bonds, derivatives, and foreign exchange) as well as markets with different trading mechanisms (dealer markets, limit order book markets, and hybrid markets), and therefore, we discuss only a few closely related papers with a particular focus on the limited inventory capacity of liquidity providers in the limit order book markets.

Naik and Yadav (2003) provide support for the view that market-makers' inventories affect market quality. Comerton-Forde, Hendershott, Jones, Moulton, and Seasholes (2010) find that market-maker financial conditions explain time variation in liquidity. Hendershott and Seasholes (2007) and Hendershott and Menkveld (2014) document market-makers' inventory management and the price pressures that arise from it for NYSE. Venkataraman and Waisburd (2007) and Menkveld and Wang (2013) document the liquidity benefits of the designated market-makers, especially for smaller firms. Raman and Yadav (2013) study limit order revisions. They find that informed traders and voluntary market-makers revise orders more often, and that changes in market prices and inventories, including inventories of other related stocks, influence order revisions. Kahraman and Tookes (2017) find that the ability to trade on margin increases liquidity; however, in crisis periods, due to massive deleveraging liquidity deteriorates (i.e., there is a downward liquidity spiral).

We find that STTs are primary intermediaries and that they actively trade among themselves in order to manage their inventories. STTs have limited inventory carrying capacity across trading days, and are similar along that dimension to HFTs who are known to end the day with flat inventory positions.[6]

Our paper is also related to the literature on market liquidity during turbulent periods. The voluntary nature of liquidity provision raises concerns about whether endogenous market-makers will be present in the market during turbulent periods, when they are most needed to provide liquidity.[7] Those who normally provide liquidity in the market stood on the sidelines during turbulent times. Kyle and Obizhaeva (2016) document five cases wherein large bets made by institutional investors led to price crashes, three of which occurred well before the rise of algorithmic trading. Kirilenko, Kyle, Samadi, and Tuzun (2017) study the role of HFTs in the Flash Crash and document that their behavior did not change during the Flash Crash,[8] while Menkveld and Yueshen (2018) argue that cross-market arbitrage (often conducted by HFTs) broke down before the Flash Crash.

These papers focus on identifying why crashes occur and on understanding the role HFTs and arbitrageurs play in this process. In our paper, in addition to establishing the reason for the fast crashes and understanding the role of traders with limited inventory capacity and cross-market arbitrage activity, we examine the role of slow-moving market-making capital in initiating recovery. Therefore, we are able to investigate the interaction between short-term traders, cross-market traders, and slow-moving standby liquidity providers at the same time.

[6] SEC (2010) and Kirilenko, Kyle, Samadi, and Tuzun (2017) use flat end-of-day inventory positions to classify traders as HFTs, while Korajczyk and Murphy (2016) and Brogaard, Hagströmer, Norden, and Riordan (2015) using a different classification criteria document above-mentioned characteristic of HFTs.

[7] There is a plethora of studies investigating the effect of HFTs on liquidity provision. Hendershott, Jones, and Menkveld (2011) show that increase in automation leads to increase in liquidity provision as well. Menkveld (2013) focuses on a single cross-venue HFT and documents that in four out of five trades, that trader was providing liquidity. Malinova, Park, and Riordan (2013) show that retail traders enjoy better liquidity due to HFTs' activity. Lyle and Naughton (2015) examine specific mechanisms through which this reduction in spreads may have occurred and why spreads did not continue to fall further with increased algorithmic trading.

[8] Brogaard, Riordan, Shkilko, and Sokolov (2014) provide evidence for HFTs' behavior around extreme market movements and show that HFTs do not cause these rapid price movements, though their liquidity demand dominates liquidity supply in case of systematic extreme price movements.We note that this paper focuses on the events of a different nature than fast crashes that normally develop over a prolonged time period – for example, the Flash Crash of May 6, 2010, which developed over 15 minutes, while Brogaard, Riordan, Shkilko, and Sokolov (2014) focus on rapid movements that occur within 10 seconds (the smallest frequency used for robustness purposes is one minute).

Further, we show that it is the market-making capital from domestic institutional investors that absorbs the liquidity shocks and stabilizes the market, even though this market-making capital is slow to get deployed. Mitchell, Pedersen, and Pulvino (2007) make a related observation using data from the convertible debt market, and Duffie (2010) examines the implications using a theoretical framework. An important difference between these papers and our paper is that we focus on the role of the slow-moving capital during fast intraday crashes, while the above-mentioned papers focus on normal market conditions.

II. Data

We use a unique database of orders and transactions for three months in 2006 (April – June) of a large anonymous firm traded on the National Stock Exchange (NSE) of India which provides us with a unique identifier for each broker-trader combination and legal classification in spot and futures markets. Our data includes detailed information on trades and quotes (the full history of the order: submission, modification, cancellation, execution). All our subsequent analysis is conducted for this one representative NSE stock.[9] We exclude three days from our sample with half-day trading sessions (April 29, May 23, and June 25, 2006).

Table I shows that there are 108,052 traders in the spot market, while in the futures market for this stock, there are only 35,951 traders during the sample period. In total, there were 137,830 traders that (i) traded in the spot market, (ii) traded in the futures market, (iii) traded in both spot and futures, or (iv) submitted the orders that were not executed during this time period. The latter category includes 8.47% of traders (11,681 traders), therefore, the number of effective traders whose orders resulted in at least one trade during this time period is 126,149. The majority of the active traders on either spot (70.65%) or futures (86.13%) markets execute their orders on both sides of the market (i.e., they both

[9] We refer to Appendix A for detailed description of the NSE market.

buy and sell). 67.47% of traders execute their orders in spot market only, while 20.17% of traders execute their orders on futures market only. Only 3.89% of traders are active in both markets; however, they are responsible for around 40% of trading activity in each of the markets.

INSERT TABLES I – II HERE

Table II shows that the majority of the order flow in the spot market is represented by new order submissions (around 71% for both buy and sell sides of the market), followed by cancellations (around 17% for the buy side and 15% for the sell side of the market) and modifications (around 13% for the buy side and 14% for the sell side of the market). Similar patterns also hold for the futures market.[10] We note that the numbers above are based on regular book orders only. Our data also include several stop-loss orders; however, none of them were executed during our sample period.

III. Trader types and their trades

The NSE classifies all traders in terms of their legal affiliations. There are three primary categories: individuals, corporations, and financial institutions; and 13 subcategories: individual traders, partnership firms, Hindu undivided families, public and private companies or corporate bodies, trust or society, MFs, domestic financial institutions, banks, insurances, statutory bodies, nonresident Indians, FIIs, and overseas corporate bodies. However, legal classifications of traders are not adequate for analyzing the role of traders in liquidity provision in different types of market conditions. Some traders could tolerate deviations from their desired inventory positions only for short periods of time, while other could tolerate persistent deviations from their target inventory positions. Therefore, we classify traders

[10] For example, momentum strategies employed by Numeric Investors (an investment-management company currently known as Man Numeric with assets under management around USD 30 billion in 2018) typically leave around 10% to 15% of orders unexecuted or cancelled (see Perold and Tierney (1997)).

based on their trading behavior and their role in the market (see Figure 1). We focus our attention on those with a short inventory-holding horizon (STTs) and examine how their inventory positions affect market liquidity, and how they manage their inventory risk. We do this based on the conjecture that STTs are continuously present in the market, whereas LTTs are present in the market only at periodic intervals and when trigger events happen.

INSERT FIGURE 1 HERE

As Figure 1 shows, on a given day, we classify traders into Small and Other. Small traders are traders whose trading volume is less than or equal to 750 shares (equivalent of one futures contract) on a given day.[11] Other traders are traders whose trading volume exceeds 750 shares on a given day. We further classify other traders by their end-of-day inventory. STTs are traders whose end-of-day inventory is less than 10% of traded volume. The LTTs are traders whose end-of-day inventory is more than 10% of traded volume. We further split LTTs into MFs and FIIs and other long-term traders (OLTTs). MFs and FII are legal entities according to the National Stock Exchange of India.[12] To determine the final category of a trader, we look at the modal classification of the trader across days and select it as the trader's category unless the mode equals "Small" trader. If a mode classification is equal to "Small" trader, we assign it as a trader category if and only if a trader is classified as Small trader on more than two-thirds of days, otherwise we use the next most frequent classification as the trader's category.[13] In other words, each trader belongs only to one category during our sample period (i.e., traders do not switch categories from one day to another day).[14]

[11]The size of a futures contract is 750 shares in our sample. Therefore, traders that trade less than 750 shares per day do not have an opportunity to use futures market for hedging purposes.

[12]We note that several MFs and FIIs end up in Small or STT groups. However, their activity during the period considered is negligible. These traders are active on average 5 (2) days in the spot (futures) market and transact on average 109 (2,375) shares per day in the spot (futures) market.

[13]We also document that the categorization of STT is persistent over time. Please see Appendix B for details.

[14]For some of the forthcoming analysis, we also split traders into those active in the spot market only,

Table III shows buy and sell trading volume for each of the three trader categories. In particular, we find that STT are responsible for 61.1% (67.3%) of the total (buy+sell) trading volume for spot (futures) market. LTT are responsible for 22.3% (31.3%) of the total trading volume for spot (futures) market. Small traders are responsible for 16.5% (1.4%) of the total trading volume for spot (futures) market. Besides that, a considerable portion of trading activity stems from STTs who are active in spot and futures markets alike: 35.6% and 28.4% for spot and futures markets, respectively, while all other trader categories are active mainly in either the spot market or the futures market. We also note that the size of the futures market is five times larger than the size of the spot market. Although the spot market is smaller than the futures market, it is more diverse in terms of market participants.

INSERT TABLE III HERE

The difference in size of the spot and futures markets is caused by a security transaction tax (an important part of transaction costs) that is much larger for the spot market (around 10 bps) than for the futures market (around 1 bps). Moreover, it is easier to take short positions in the futures market than in the spot market. Overnight short positions in the spot market was not allowed during our sample period except through participatory notes, but this way of borrowing shares was available to very few investors, mainly FIIs.

INSERT TABLE IV HERE

Table IV shows average daily trading volume between each possible trader-pair (i, j). We document that STTs are the most frequent counterparties for LTTs and Small traders, for the spot and futures markets alike. Roughly 26.4% (41.6%) of the average daily volume for the spot (futures) market is between STTs and LTTs. Roughly 21.7% (1.9%) of the total daily trading volume for the spot (futures) market is between STTs and Small traders,

those active in the futures market only, and those active in both markets. The latter category allows us to draw conclusions on cross-market arbitrage activity.

with Small traders being not that active in the futures market. The volume traded among STTs is 37.1% and 45.4% of the total daily trading volume for the spot and futures markets, respectively. Overall, STTs are responsible for around 85.2% (88.9%) of the daily trading volume for the spot (futures) market. To summarize, STTs are the hub for the majority of the transactions and the primary liquidity providers in the market.

The proportion of trading activity among STTs themselves is in line with Reiss and Werner (1998), who report that inter-dealer trading in 1991 on the London Stock Exchange accounts for on average 24% and can be as high as 65% of all trades when dealer inventories are high. However, if we consider HFTs as a natural evolution of STTs once algorithmic trading is allowed, we document twice-as-high total trading activity among such traders as reported by Brogaard, Hendershott, and Riordan (2014), who document that in 2009, on the NASDAQ (a dealer market with elements of the limit order book), HFTs overall were responsible for 42% (18%) of volume for large (small) stocks. Moreover, Johnson, Van Ness, and Van Ness (2017) document (using the same dataset, but for NASDAQ-listed stocks only) that HFTs are responsible for 47% of trading volume; however, only 8% of it is among HFTs themselves, as compared to our estimate of 37% among STTs for the spot market.

IV. Stock price fast crashes and recoveries

In this section, we identify stock price fast crashes and study the behavior of different types of traders during the four-day window surrounding crashes.

A. *Identification of the fast crashes*

We identify fast crashes using drift-burst statistics developed by Christensen, Oomen, and Renò (2016)[15], and also used by Bellia, Christensen, Kolokolov, Pelizzon, and Renò

[15] We thank the authors for sharing the code for the estimation procedure as well as the dataset containing critical values of the drift-burst statistic.

(2018):

$$
\begin{aligned}
T_t &= \sqrt{\frac{h_\mu}{K_2}}\frac{\mu_t}{\sigma_t} \\
\mu_t &= \frac{1}{h_\mu}\sum_{i=1}^{n}\left(K\left(\frac{t_{i-1}-t}{h_\mu}\right) r_{t_{i-1}}\right) \\
\sigma_t &= \sqrt{\frac{1}{h_\sigma}\sum_{i=1}^{n}\left(K\left(\frac{t_{i-1}-t}{h_\sigma}\right) r^2_{t_{i-1}}\right)} \\
K(x) &= \exp(-|x|)1(x \leq 0) \\
K_2 &= \int_R K^2(x)dx
\end{aligned}
\tag{1}
$$

Under the null of no drift burst T_t follows standard normal distribution; however, when there is a drift burst, $|T_t|$ goes to infinity. We estimate drift-burst statistics for the mean bandwidth (h_μ) of 15 minutes and the volatility bandwidth (h_σ) of 45 minutes. This implies that we are interested in the fast crashes that develop, on average, within 15 minutes, similar to the Flash Crash of May 6, 2010. In the end of each one-minute interval, we compute the drift-burst statistics based on the one-second mid-quote returns for the spot market. Given that we are interested in the crashes, we focus our attention on negative drift-burst statistics. We mark one-minute intervals when the absolute value of the drift-burst statistics exceeds its critical value at 95% confidence level as troughs of the crash. We account for the multiple tests as in Christensen, Oomen, and Renò (2016). In our sample, we detect eight such troughs. The drift-burst statistic by itself does not tell us whether the crash is reverted. Therefore, we look at the cumulative returns 30 minutes before and after the trough. We select only those crashes that recover by at least 50%. After applying the recovery condition, only two fast crashes remain: those that took place on May 19, 2006, and May 22, 2006. On May 19, 2006, the trough of the crash is at 10:38 a.m. On May 22, 2006, the trough of the crash is at 11:52 a.m.[16]

[16]For further analysis, we focus our attention on the four days surrounding the crash days from May 16

INSERT FIGURE 2 HERE

Figure 2 shows the spot and futures mid-quotes evolutions during the trading day together with NIFTY prices (median over a one-minute interval) for the two days days on which the fast crashes happened. On May 19, we observe two events that look like a fast crash followed by a fast recovery. Indeed, on May 19, we identify two troughs based on the drift-burst statistic. However, only during the first event did the crashes develop and revert quickly enough. During the 30 minutes before the trough of the first crash, price fell by 7.9% and recovered by 5.1% only (reversal of 64.5%) in the 30 minutes that followed. However, during 30 minutes before the trough of the second crash price fell by 6.1% and recovered in the next 30 minutes by only 0.6% (9.1% reversal). Put differently, during the second event on May 19, prices did not fall and recover fast enough to be classified as a fast crash. On May 22, during the 30 minutes before the trough, prices fell by 10.2% and recovered in the next 30 minutes by 7.0% (reversal of 68.4% reversal). This fast crash was also characterized by a trading halt (from 11:56 a.m. to 12:56 p.m.) before market recovery took place. We also note that the two fast crashes were accompanied by similar movement in the NIFTY index, though it was less pronounced.

B. *Traders' behavior during fast crashes*

We investigate trader behavior by looking at the trading volume between the different categories during the two fast crashes over the total trading volume on a given day. In particular, for each one-minute interval t on day k, we compute the trading volume, Vol_{ijkt} (in number of shares), coming from each possible trader-pair (i, j) relative to the total trading volume on day k, and regress it on trader-pair dummies (D_{ij}, where i refers to selling category and j to buying category) and their interaction with dummy variables for market drawdowns

till May 25. We note that May 18 and May 23 are either missing from our data or only include trades for the first 30 minutes of the trading session.

($Down_{kt}$) and recovery (Up_{kt}) periods, day fixed effects (FE_k), and half-hour time dummies (TD_b). More formally:

$$\begin{aligned} \frac{Vol_{ijkt}}{\sum_{(i,j)} Vol_{ijk}} = & \sum_{(i,j)} \beta_{ij} D_{ij} + \sum_{(i,j)} \gamma_{ij} Down_{kt} D_{ij} + \sum_{(i,j)} \delta_{ij} Up_{kt} D_{ij} + \\ & + \sum_{k} \alpha_k FE_k + \sum_{b} d_b TD_b + \epsilon_{ijkt} \quad for \;\; all \;\; (i,j) \end{aligned} \tag{2}$$

where $Down_{kt}$ (Up_{kt}) is equal to one for – (+) 30 minutes from the trough of the fast crash and zero otherwise.

Table V shows the results of the trading-activity regression estimation around the two fast crashes in our sample (May 19, 2006, and May 22, 2006) for spot and futures markets. We note that in Table V we focus on one-minute trading volume relative to the daily trading volume, and thus the numbers reported in the Table V are not directly comparable to the numbers reported in Table IV where we focus on daily trading volume per each category.

INSERT TABLE V HERE

Panel A of Table V shows that during the market drawdown period, STTs significantly increase their buying from LTTs by 5.34 basis points of total daily volume for the spot market (i.e., their buying from LTTs more than doubled relative to the normal period), while LTTs do not increase trading activity among themselves. We acknowledge that STTs buying from LTTs during the fast crash was similar to their buying from LTTs during the recovery period. In summary, STTs tried to accommodate the volume sold by LTTs, but STTs are not able to stop market drawdown. At the same time, during the drawdown period, STTs increase trading among themselves by 5.87 basis points of total daily volume (i.e., their trading among themselves is 1.5 times larger than during the normal period). This finding is in line with "hot potato" trading increasing during the crash, when traders with limited inventory capacity tried to unload their inventory to other market participants to manage inventory risk. Interestingly, according to CFTC and SEC (2010), HFTs engaged in "hot potato" trading during the Flash Crash of May 6, 2010.

Panel A of Table V shows that during market recovery after the fast crash, there is a significant increase in trading activity between LTTs by 7.31 basis points of total daily volume in the spot market (i.e., trading activity between LTTs tripled relative to the normal period). STTs unloaded their inventory accumulated during market drawdown to LTTs (a significant increase of selling volume by 7.81 basis points of total daily volume – or, in other words, STTs' selling to LTTs almost tripled) during the recovery period.

Panel B of Table V repeats the analysis discussed above for the futures market. During drawdown periods, STTs increase their buying from LTTs by 3.90 basis points of total daily volume (i.e., their buying from LTTs increased 1.5 times relative to the normal period). LTTs decrease trading among themselves during the drawdown period in the futures market by 1.28 basis points of total daily volume (i.e., their trading among themselves decreased by one quarter relative to the normal period). STTs also used the recovery period to unload inventory bought from LTTs (a significant increase of selling volume by 6.25 basis points of total daily volume – or, in other words, STTs' selling to LTTs almost doubled) during the recovery period.

Remarkably, during both drawdown and recovery periods, STTs increased their trading activity in the opposite direction to the market movement, and therefore, provided liquidity to the market when necessary. Our findings are in line with Brogaard, Riordan, Shkilko, and Sokolov (2014), who document that HFTs provide liquidity in case of a single stock experiencing an extreme price movement by absorbing order flow from non-HFTs.

We observe that trading patterns in the spot and futures markets are different. In particular, we do not observe a remarkable increase in trading among LTTs themselves during the recovery period in the futures market. In order to uncover the reason for this difference we split the LTT category and look at the activity of FIIs and MFs on the crash days.

Unfortunately, we cannot estimate equation (2) by enriching it with FII and MF categories due to multicollinearity problem: FII activity is concentrated during the drawdown period and MF activity is concentrated during the recovery period, but we also provide graphical representation of the behavior of MFs and FIIs (see Figure 3). Figure 3 shows that FIIs' selling in the spot market coincides with the fast crashes (see Panels A and C), while buying by MFs in the spot market is followed by the market recovery (Panels B and D). These graphs are consistent with the stabilizing role of the slow-moving capital (see Duffie (2010)). However, there was no selling pressure by FIIs in the futures market. We also emphasize that FIIs take opposite positions in spot and futures markets; however, these positions are established by different traders within the FII group, so they are not driven by cross-market arbitrage activity.

INSERT FIGURE 3 HERE

To provide further evidence on ex-ante liquidity provision by the different categories during fast crashes, we look at the limit order book and plot the number of shares quoted within 100 basis points of the mid-quote (see Figures 4 – 5). We observe that STTs are still present during the fast crash period within 100 basis points from the mid-quote, although their presence is less profound than during normal periods (which is in line with quoted spread widening during the turmoil periods). Further, the behavior of FIIs and MFs in the spot market are in line with FIIs causing the fast crash and MFs helping price recovery. In particular, we observe that FIIs quoted a lot of depth at the ask side of the limit order book within 100 bps of the mid-quote in the spot market, while MFs quoted a lot of depth at the bid side of the limit order book within 100 bps of the mid-quote in the spot market. Overall, this is consistent with MFs in the spot and futures markets and FIIs in the futures market being slow-moving liquidity providers. We provide a more detailed analysis on the role played by MFs and FIIs in Section IV.D.

INSERT FIGURES 4 – 5 HERE

Figures 3 – 5 suggest that the crashes were driven by a selling pressure from FIIs in the spot market, while the behavior of FIIs in the futures market is not related to the price patterns. In other words, the futures market followed the spot market. Even though the two prices came down together, there were not fully synchronized and there were apparent cross-market arbitrage opportunities, as we show below. We follow Menkveld and Yueshen (2018) and construct two proxies for cross-market arbitrage between the spot and futures markets:

$$Proxy1_{k,t} = max(0, max(Bid^{spot}_{k,t}, Bid^{fut}_{k,t} - min(Ask^{spot}_{k,t}, Ask^{fut}_{k,t})) \tag{3}$$

$$Proxy2_{k,t} = \frac{\sum_{i=spot,\ fut} (Ask^{i}_{k,t} - \overline{Ask_{k,t}})^2 + (Bid^{i}_{k,t} - \overline{Bid_{k,t}})^2}{4} \tag{4}$$

$Bid^{spot}_{k,t}$ ($Ask^{spot}_{k,t}$) is the futures price that we compute using a call money rate based on the best bid (ask) price in the spot market at time t on day k. $Bid^{fut}_{k,t}$ ($Ask^{fut}_{k,t}$) is the best bid (ask) in the futures market at time t on day k. $\overline{Bid_{k,t}}$ ($\overline{Ask_{k,t}}$) is the average between the futures price that we compute using a call money rate based on the best bid (ask) price in the spot market and the best bid (ask) in the futures market at time t on day k.

Figure 6 plots a time series of the two proxies for arbitrage opportunities for May 19 and May 22 together with the spot mid-quote (median by minute). We observe that there are more opportunities for arbitrage during the crash and recovery periods of the market. Menkveld and Yueshen (2018) document similar patterns for the Flash Crash of May 6, 2010. This is consistent with cross-market arbitrage trading not being backed by sufficient capital. Thanks to our unique database, we could argue that this result is in line with the evidence provided in Table III that most of the cross-market traders are STTs (i.e., even the cross-market traders do not have enough capital capacity to exploit the arbitrage opportunities).

INSERT FIGURE 6 HERE

Further, we investigate whether STTs change their behavior during crashes. We follow Kirilenko, Kyle, Samadi, and Tuzun (2017) and estimate the following equation that measures the sensitivity of the inventory changes, $\triangle Inv_{ikt}$, of trader category i (STT, FII, and MF) during time interval t on day k to the contemporaneous mid-quote return (Ret_{kt}) during market drawdown ($Down_{kt}$) and recovery (Up_{kt}) periods controlling for lagged spot/futures inventory ($Inv_{ik,t-1}$) and lagged changes in the spot /futures inventory ($\triangle Inv_{ik,t-1}$), day fixed effects (FE_k), and time fixed effects (TD_b):

$$\begin{aligned}\triangle Inv_{ikt} =& \beta_1 Ret_{kt} + \beta_2 Down_{kt} Ret_{kt} + \beta_3 Up_{kt} Ret_{kt} + \\ &+ \beta_4 Down_{kt} + \beta_5 Up_{kt} + \beta_6 \triangle Inv_{ik,t-1} + \beta_7 Inv_{ik,t-1} + \\ &+ \beta_8 Down_{kt} \triangle Inv_{ik,t-1} + \beta_9 Down_{kt} Inv_{ik,t-1} + \\ &+ \beta_{10} Up_{kt} \triangle Inv_{ik,t-1} + \beta_{11} Up_{kt} Inv_{ik,t-1} + \\ &+ \sum_k \alpha_k FE_k + \sum_b d_b TD_b + \epsilon_{ikt}\end{aligned} \tag{5}$$

where $Down_{kt}$ (Up_{kt}) is equal to one for – (+) 30 minutes from the trough of the fast crash and zero otherwise.

INSERT TABLE VI HERE

In Table VI, we document the estimation results of equation (5). The first column reports the sensitivity of STT as a group (STT-All) inventories to the spot and futures returns (Panel A and Panel B, respectively). We show that for STT-All, the coefficient in front of the spot return is positive and significant, indicating that as a group, STT-All move with the spot market (Panel A), and the coefficient in front of the futures return is negative and significant, indicating that STT-All are contrarian (Panel B). The result for the spot market is in line with Kirilenko, Kyle, Samadi, and Tuzun (2017), who document that HFTs are moving with the market during normal times (based on the coefficient in front of contemporaneous returns). However, this comparison is misleading, as some STTs trade in either the spot or futures market only, while other STTs trade across both markets. Hence, we split STT-All into three groups: STT-Spot, STT-Futures, and STT-Both.

The second column of Panel A of Table VI reports the sensitivity of STT-Spot inventories with respect to the spot return. We show that this coefficient is negative and significant, indicating that STT-Spot are contrarian (i.e., in general, they provide liquidity). During market drawdown, STT-Spot inventory sensitivity to the spot return does not change since the coefficient is not significant. However, during market recovery, STT-Spot inventory sensitivity to the spot return becomes zero (the interaction coefficient between dummy for the recovery and the spot return is positive and significant, and is of the same magnitude as the coefficient of the spot return itself). That is, STT-Spot withdraw from the market, perhaps due to exhausting their inventory capacity. In Section IV.C.2, we investigate this issue in depth.

The second column of Panel B of Table VI performs the same analysis for STT-Futures. In this case, the coefficients are not statistically significant, indicating that as a group, STT-Futures do not exhibit any particular pattern of inventory sensitivity to the futures return.

The third column of Table VI reports the sensitivity of STT-Both inventory with respect to spot return (Panel A) and futures return (Panel B). We show that in general, STT-Both have a positive and significant coefficient in the spot market and a negative and significant coefficient in the futures market – i.e., STT-Both are taking opposite positions in spot and futures markets consistent with cross-market arbitrage activity. During market drawdown and recovery, STT-Both become contrarian in the spot market and less contrarian in the futures market.[17] This is consistent with them taking the same positions across both markets

[17] The result for the spot market is consistent with contemporaneous results of Kirilenko, Kyle, Samadi,

(i.e., STT-Both did not seem to engage in cross-market arbitrage activities during the fast crashes), and thus cross-market arbitrage broke down during the fast crashes.

The analysis performed following Kirilenko, Kyle, Samadi, and Tuzun (2017) considers STTs as a group and does not distinguish between different traders within the STT category. We open up the STT category and investigate the behavior of each individual trader (i.e., whether a trader withdraws from the market during the market drawdown period, and whether a trader hits her inventory constraints during crash days) in Section IV.C.

Table VI also reports inventory sensitivity for FIIs and MFs. It is important to emphasize that FIIs and MFs who trade in the spot and futures markets are different traders (i.e., they do not trade in both markets). Hence, both FIIs and MFs are not engaging in cross-market arbitrage. We document that FIIs move with the market during normal times and intensify such behavior during market drawdown in the spot market, while in the futures market, FIIs move with the price during normal times and become contrarian during drawdowns and recoveries.

We document that MFs inventories seem to be insensitive to the price movement neither during normal nor during turbulent periods for the spot and futures markets alike. Due to the nature of MFs' slow-moving capital, they do not change their inventories as frequently as one-minute change in returns. Thus, we do not find any significant coefficients for MFs. Hence, we provide a more detailed analysis on the role of both FIIs and MFs in Section IV.D.

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and Tuzun (2017) for HFTs. Therefore, based on the contemporaneous inventory sensitivity to spot/futures returns, we do observe a change in STTs' behavior during market drawdown and recovery periods. Unfortunately, trading activity in our data is not frequent enough to sample at as high frequency as in Kirilenko, Kyle, Samadi, and Tuzun (2017), and thus we are not able to perform a joint test on the changes of inventory sensitivity to contemporaneous and lagged returns during market drawdown and recovery periods, which is the main test performed by Kirilenko, Kyle, Samadi, and Tuzun (2017).

C. The role of STTs during fast crashes

In this section, we argue that STTs could not prevent fast crashes from happening due to limited inventory capacity. First, we show that STTs tried to "lean against the wind" by documenting their cash flows during the crash days, but could not do so (see Section IV.C.1). Second, we show that STTs indeed were inventory constrained during the crash days (see Section IV.C.2).

C.1. Cash flows of STTs

In this section, we provide evidence of whether STTs "lean against the wind." Given that STTs tend to end each day with flat positions, we make a simplifying assumption that at the end of the day, they do not have any positions to liquidate, and hence, each day, they start with a zero-inventory position. We note that we compute aggregate cash flows for the STT category. Hence, we do not exclude the possibility for vast heterogeneity within the STT category. In particular, for each one-minute interval t on day k with at least one transaction, we compute cumulative cash flow for STTs, $Cash\ Flow_{STTkt}$, which increases with sell transactions and decreases with buy transactions, and regress it on dummy variables for market drawdowns ($Down_{kt}$) and recovery (Up_{kt}) periods, day fixed effects (FE_k), and half-hour time dummies (TD_b):

$$Cash\ Flow_{STTkt} = \gamma Down_{kt} + \delta Up_{kt} + \sum_{k} \alpha_k FE_k + \sum_{b} d_b TD_b + \epsilon_{kt} \tag{6}$$

where $Down_{kt}$ (Up_{kt}) is equal to one for – (+) 30 minutes from the trough of the fast crash and zero otherwise.

INSERT TABLE VII HERE

Table VII shows the results of the cash flow regression estimation around the two fast crashes in our sample (on May 19, 2006, and on May 22, 2006) for the spot and futures markets. Panels A and B of Table VII report the results of the cash flow analysis (in millions of rupees) for the spot and futures markets, respectively. We observe that cash flows decrease during the market drawdown period and increase during the market recovery period for both markets alike. Although we lack statistical power for this test, to further support our hypothesis, we depict the cumulative cash flows of STTs during the two fast crash days (Figure 7). We find that cumulative cash flows for STTs decrease during market drawdowns and increase during recovery periods.

INSERT FIGURE 7 HERE

C.2. Inventory capacity of STTs

In this section, we provide evidence that STTs hit their inventory limits during the crash days. First, we show summary statistics of STTs' participation during the crash days. Second, we present dynamics of the inventory capacity of STTs at daily and intraday level (the latter for the two crash days only).

INSERT FIGURE 8

Figure 8 shows the number of STTs that were active either on May 19, May 22, or both for the spot and futures markets (the latter one is reported in parentheses). We divide STTs into groups based on whether they belong to the top group of STTs or not, whether they are active during the market drawdown period or not, and whether they were inventory constrained or not.

We define top STTs as those with large trading volume who jointly generate 50% of STT trading volume. There are only 27 (64) top STTs out of 6,547 (20,524) STTs in the spot (futures) market (see Appendix B for details). Naturally, having one of the top STTs hitting its inventory limits is more problematic for the market than one of the smaller STTs hitting its inventory limits.

We define STTs as inventory-constrained STTs if the trader's maximum of absolute value of one-minute median inventory, either on May 19 or on May 22 (or both), is above this traders' 95th percentile of the maximum of the absolute value of one-minute median inventory over the sample period, excluding May 19 and May 22.

We show that on the two crash days, there were 1,099 STTs on the spot market. Out of them, 26 traders were from the top group, with 19 of the top traders actively engaging in cross-market trading. Out of 19 top traders active on both markets, 17 participated during the crash with 27% of them hitting their inventory constraints. Overall, 22 (17 + 5) traders from the top group of STTs participated during the market drawdown, with 27% of them hitting their inventory constraints. Out of the smaller STT group, 20% were active on both markets, but less than half of the smaller cross-market traders were active during the crash (86 traders). Moreover, 51 of these 86 traders were constrained during the crash days. Overall, out of the smaller STT group only 441 (86 + 355) traders participated during the market drawdown (41%), with 275 (51 + 224) of them hitting their inventory constraints, and 632 (125 + 507) traders preferring to stay away from the market during the crash. Overall, more than 50% of STTs disappeared from the market during the turbulent periods, and 60% of those STTs who continued to participate in the market during the turbulent periods hit their inventory constraints. STTs in the futures market exhibited similar participation patterns. This detailed analysis shows, therefore, that not all STTs behave in the same way during crashes as they do during normal times.

Figure 9 plots time-series of the STTs' inventory capacity for the daily frequency over the whole sample period (Panels A and B) and intraday inventory capacity on May 19 and May 22 (Panels C and F). At the daily frequency, inventory capacity is defined as follows. First, for each day, we compute the maximum absolute one-minute median inventory for each trader. Second, we normalize this number by the maximum for the whole sample period, excluding May 19 and May 22. Finally, we take the average across all traders. Hence, the larger the measure, the more constrained STTs are. Panels A and B of Figure 9 show the time series of daily inventory capacity measures for the spot and futures markets, respectively. For the spot market, the inventory capacity measure reached 80% (100%) on May 19 (May 22), while for other days in the sample period, it never exceeded 20%. For the futures market, the picture was similar, although less extreme.

Though most traders have exhausted their inventory capacity during the crash days, it might be that they reach their limits during different times of the day. Therefore, Panels C and F plot STTs' intraday capacity measure, which is an average ratio of the absolute value of one-minute median inventory to the whole-sample maximum of the absolute value of one-minute median inventory, excluding May 19 and May 22, for the spot and futures markets. We observe that capacity measure increased with the evolution of the crash and stabilized during the recovery period. On May 19, due to the second event, the capacity measure continued to increase after recovery had taken place. On May 22, the capacity measure decreased slowly after the recovery for the spot market and remained constant for the futures market.

INSERT FIGURE 9 HERE

Overall, this confirms that STTs tried to "lean against the wind" during the two crashes in our sample. However, their limited inventory capacity did not allow them to stop the crash.

D. *The role of MFs and FIIs during fast crashes*

In the earlier sections, we investigated the role of STTs during crashes and recoveries in the spot and futures markets. We now proceed to examine the role of MFs and FIIs. We first examine whether MFs and FIIs in our sample are opportunistic buyers and sellers, thus systematically providing liquidity throughout our sample period. For that purpose, we plot MFs' and FIIs' cumulative end-of-day inventory position since the beginning of our sample period and the minimum and maximum trading price observed during the day. We note that overnight short-selling was not allowed in the spot market, hence negative inventories in the spot market should be interpreted as a decrease of the starting inventory position.

INSERT FIGURE 10 – 11 HERE

Panel A of Figures 10 – 11 show that in the spot market, FIIs move with the price, while MFs in our sample are indeed opportunistic traders:[18] they buy when the price goes down and sell when the price goes up. Panel B of Figures 10 – 11 show that in the futures market, both FIIs and MFs are opportunistic traders, but their activity is concentrated around extreme market movements only. Panels C and D of Figure 11 show the end-of-day cumulative inventory position for MFs that were active on the crash days. We observe that these MFs were not active before the crash; they bought during the crash and held their inventory position till the end of our sample period. This behavior suggests that they were standby liquidity providers and that it took some time for them to deploy their market-making capital to provide liquidity.

We now look in more detail at the individual behavior of MFs and FIIs that were active during the crash days. Tables VIII and IX provide summary statistics for the participation of different trader categories in the spot and futures markets, respectively, during the crash days. On the spot market, we show that on the two crash days, there were 9 FIIs and 23 MFs (Panels A and B of Table VIII). FIIs consistently sold during drawdown, recovery, and normal periods. MFs consistently bought during drawdown, recovery, and normal periods. We acknowledge that some FIIs bought and some MFs sold during the crash days on the spot market, but these amounts are negligible relative to FIIs' and MFs' total trading volume during the crash days. FIIs active on the crash days bought 15,000 and sold 650,231 shares on May 19 and May 22 (i.e., they primarily sold); on other days, in total, they bought 497,817

[18] Perold and Tierney (1997) document that Numeric Investors behaved in this way when taking positions based on their fair-value model.

and sold 537,155 shares, therefore buying and selling approximately the same number of shares. MFs active on the crash days bought (sold) 578,509 (81,269) shares on May 19 and May 22; on other days, in total, they bought (sold) 83,214 (150,250) shares. Moreover, we show that during the drawdown period, FIIs sold 142,177 shares and MFs bought 64,880. During the recovery period, FIIs sold an additional 185,457 shares and MFs bought 171,312. Finally, it is important to stress that by looking at individual traders' IDs, we can ensure that MFs who were the main net buyers during the crash had little trading activity on other days. This is consistent with slow-moving MF capital.

Panels C and D of Table VIII show that other LTTs and STTs active on the crash days buy and sell approximately the same number of shares during the crash, recovery, and normal periods. The net buying effect of their trading activity is not enough to initiate recovery. They are also active on other days in our sample period.[19]

Table IX provides summary statistics for FIIs' and MFs' participation in the futures market during the crash days. Panels A and B of Table IX show that both FIIs and MFs mainly bought throughout the crash days. While MFs active in the futures market on the crash day limited their activity to these two days, FIIs were also active on other days in our sample period. We show that FIIs have different behavior in the spot and futures markets; however, these are two different set of traders, and therefore FIIs do not engage in cross-market arbitrage. Panels C and D of Table IX show that the behavior of OLTTs and STTs in the futures market is similar to their behavior in the spot market.

INSERT TABLES VIII – IX HERE

In Figures 10 – 11, we showed that MFs in the spot and futures markets and FIIs in the futures market systematically act as opportunistic traders. There might be multiple reasons that give rise to such trading patterns. In the following analysis, we test one possible

[19]Given that most top STTs are active during the crash days, the activity of these traders represents the majority of STTs' trading activity on other days as well.

explanation of this behavior. If MFs in the spot and futures markets and FIIs in the futures market trade as if they had limit prices for buying and selling based on some notion of "fair-value", then it should naturally lead to opportunistic trading through patient buying (selling) at the volume-weighted average price below (above) than the volume-weighted price of the STTs (i.e., there should be better quality of trade execution).

To evaluate the quality of trade execution, for each trader l on day k, we compute the volume-weighted average price of its transactions relative to the daily volume-weighted average price of all transactions for the buy and sell side separately and regress it on dummy variables that equal one if a trader belongs to either the FII, MF, or OLTT category; on a dummy variable that equals one for traders active the crash days, the interaction between the; and day fixed effects (FE_k):[20]

$$\frac{VWAP_{lk}}{VWAP_k} = \sum_k \alpha_k FE_k + \beta_1 FII_{lk} + \beta_2 MF_{lk} + \beta_3 OLTT_{lk} + \beta_4 FII_{lk} * Active_l + \\ + \beta_5 MF_{lk} * Active_l + \beta_6 OLTT_{lk} * Active_l + \beta_7 Active_l + \epsilon_{lk} \quad (7)$$

INSERT TABLE X HERE

Panel A of Table X shows for the specification, including interaction variables, that MFs (OLTTs) buy a stock at a price relative to the daily VWAP of all transactions that is 0.22% (0.14%) lower than the volume-weighted average price of STTs and Small traders in the spot market, while FIIs active on the crash days buy at a price 0.27% higher than the volume-weighted average price of STTs and Small traders in the spot market. FIIs also sell stock at a price the price relative to the daily VWAP of all transactions that is 0.31% lower than the volume-weighted average price of STTs and Small traders in the spot market. In other words, MFs and OLTTs are patient buyers, while FIIs are impatient sellers in the spot market, and

[20] We do not use aggregation for trader categories as within each category, there might be traders with different strategies.

this effect is not solely driven by those MFs and FIIs active during the crash days; rather, it is a general characteristic of the traders that belong to these categories during our sample period. Panel B of Table X presents the same analysis for the futures market. We show that in the futures market, both MFs and FIIs are patient buyers with a discount of 0.74% and 0.30%, respectively, though FIIs active on crash days got a smaller discount than FIIs that are not active on the crash days got on their buy transactions. Hence, MFs in the spot and futures markets and FIIs in the futures market are slow-moving not because they are slow to react to the market signal, but because they wait till the price hits their buying limit estimate from the "fair-value" model.

So far, we show that MFs in the spot and futures markets and FIIs in the futures market (i) are slow-moving and patient traders (ii) and get a better quality of trade execution. We next investigate whether MFs in the spot and futures markets and FIIs in the futures market Granger-cause the recovery versus whether recovery Granger-causes MFs in the spot and futures markets and FIIs in the futures market to appear on the market. In order to do that, we estimate the vector-autoregression model on one-minute mid-quote returns and the marketable order imbalance from different trader groups. We use BIC criterion to decide on the number of lags, n. We compute the marketable order imbalance for each trader group i as a ratio of buy volume initiated by trader group i minus sell volume initiated by this trader group i, and scale it with overall buyer- minus seller-initiated volume in the market during a one-minute time interval t. In order to determine which order initiates the transaction, we match trades with respective quotes and compare the timestamps of the two sides of the transaction. The order with the latest timestamp is the one that initiates the transaction.[21]

$$MOIB_{i,t} = \frac{Buyer\ initiated\ volume_{i,t} - Seller\ inititated\ volume_{i,t}}{Buyer\ initiated\ volume_{t} + Seller\ inititated\ volume_{t}} \tag{8}$$

[21] In case orders on the two sides of the transaction have the same timestamp, we cannot determine which order is initiating the trade. However, there are very few such unclassified cases: 0.76% and 1.22% of trading volume for the spot and futures markets, respectively.

$$
\begin{aligned}
Ret_t &= \alpha + \sum_{lag=1}^{n} \beta_{0,lag} Ret_{t-lag} + \sum_{lag=1}^{n} \sum_{i} \beta_{i,lag} MOIB_{i,t-lag} + \epsilon_t \\
MOIB_{i,t} &= \alpha + \sum_{lag=1}^{n} \beta_{0,lag} Ret_{t-lag} + \sum_{lag=1}^{n} \sum_{i} \beta_{i,lag} MOIB_{i,t-lag} + \epsilon_t
\end{aligned}
\tag{9}
$$

Panels A and B of Table XI present the results of Granger-causality tests (for brevity, we report only those test results that we are interested in) for the spot and futures markets, respectively. For the spot market, we show that the marketable order imbalance from FIIs and MFs Granger-cause returns on the crash days at a 10% significance level, while returns do not Granger-cause the marketable order imbalance of either FIIs or MFs. On the contrary, during non-crash days, the marketable order imbalance of MFs and FIIs do not Granger-cause returns, nor vice versa. This is consistent with FIIs in the spot market causing a crash and MFs in the spot market causing the recovery.

For the futures market, neither FIIs' marketable order imbalance nor that of MFs Granger-cause returns on crash days, while returns Granger-cause FIIs' marketable order imbalance on crash days. This is indicative of the crash and recovery starting in the spot market and the futures market catching up later.

We find that MFs induce the recovery process in the spot market; however, it takes a while for them to step in. They act as standby liquidity providers who are slow in deploying their market-making capital. Our statistical tests confirm that buying by MFs leads to recovery, but recovery does not lead MFs to buy. Our findings are consistent with Keim (1999), who expresses the view that MFs are natural liquidity providers in the stocks they hold, and Da, Gao, and Jagannathan (2010), who find that the Dimensional Fund Advisors Micro Cap fund added 20.5 basis points per quarter to performance through liquidity provision.

Finally, we investigate whether the combined behavior of the different traders has a significant impact on price discovery. Therefore, we perform a vector-autoregression analysis across the spot and futures markets with number of lags selected by BIC criteria:

$$
\begin{aligned}
Ret_{spot,t} &= \alpha + \sum_{lag=1}^{n} \beta_{1,lag} Ret_{spot,t-lag} + \sum_{lag=1}^{n} \beta_{2,lag} Ret_{fut,t-lag} + \epsilon_t \\
Ret_{fut,t} &= \alpha + \sum_{lag=1}^{n} \beta_{1,lag} Ret_{fut,t-lag} + \sum_{lag=1}^{n} \beta_{2,lag} Ret_{spot,t-lag} + \epsilon_t
\end{aligned}
\tag{10}
$$

Panel C of Table XI reports Granger causality test for equation (10). We show that during normal times, the futures market Granger-causes spot market movement in line with the trading volume almost five times larger in the futures market than in the spot market. However, during crash days, returns in both markets Granger-cause each other. This is in line with the fact that large selling pressure from FIIs occurred only in the spot market, while both markets experienced fast crashes.

V. Conclusion

Stock price crashes, though infrequent, do occur with adverse consequences. The Flash Crash of May 6, 2010, has drawn the attention of regulators and exchanges to the need to understand the role of different types of traders during crashes and their recoveries. In particular, there is an ongoing debate in the literature on the role of high-frequency traders (HFTs), important traders who contribute to a large fraction of the trading volume and who are characterized by their superior speed and limited inventory carrying capacity.

Based on a dataset with unique identifiers for each broker-dealer-trader combination across the spot and futures markets, along with their legal entity type, we provide a comprehensive analysis of the interactions among different types of traders. We examine the role of short-term traders (STTs), who, like HFTs, carry little intraday and overnight inventories; cross-market traders (a subset of STTs), who trade across the spot and futures markets; Mutual Funds (MFs), who hold a large inventory of stocks and can tolerate deviations from their desired inventory positions for a longer period of time; and Foreign Institutional Investors

(FIIs), who trade based on their global perspective.

We find that MFs and FIIs trade mainly in the spot market or the futures market, but not in both markets in our sample. We find that STTs are the major liquidity providers in both the spot and futures markets – they have a major share of the trading volume as well as the orders on both sides of the book in the proximity to the best bid-offer level. MFs are patient traders trading much less than STTs, but with better execution quality. In line with the previous literature where large sell orders initiate crashes, we find that large sell orders by FIIs put a downward pressure on the stock price. Buying by STTs was not enough to prevent the fast crashes observed in our sample and their buying slowed down as the crash progressed. During the first crash, MFs, though slow to move in, started buying in sufficient quantities to help stop the crash and initiate price recovery. In the second crash, trading was halted. When trading resumed, MFs once again started buying in sufficient quantities to promote the subsequent price recovery.

We show that during normal times, changes in futures price Granger-caused changes in spot price. This should be expected, since it was easier to take long as well as short positions in futures; trading costs were higher in the spot market, where overnight short positions were not allowed; and futures had higher (five times) trading volume than spot. However, both fast crashes as well as their recoveries originated in the spot market and spilled over into the futures market. This shift in causality during crashes and recoveries resulted in Granger-causality going both ways during the two crash days (i.e., spot and futures price movements Granger-caused each other).

Our findings emphasize the role of well-capitalized standby liquidity providers like mutual funds who can redeploy capital into the market when the rewards are sufficient, thereby providing much needed liquidity. This process takes some time, since such liquidity providers have to understand the reasons for the crash and may also require a large price concession. Circuit breakers, while providing the needed time for standby liquidity providers to move in, may not provide the necessary incentives. To the extent that there are no alternative mechanisms to provide the necessary incentives for attracting standby liquidity providers, rare crashes may be inevitable in markets where competitive forces have resulted in thinly capitalized intermediaries (STT) being the de facto liquidity providers. As such our findings suggest that the ample and cheap liquidity during normal times necessarily comes at the cost of infrequent crashes and that no obvious regulatory remedy exists that would lead to a pareto improvement of this trade-off.

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Table I Number of traders

This table shows the number and proportion of traders who are active in the spot and futures markets. We divide traders into those who execute trades on both sides of the market, or on only one side of the market, or do not execute trades at all, separately for the spot and futures markets. We also divide traders into those who execute trades in both spot and futures markets, only in the spot market, only in the futures market, or do not execute trades at all. For the futures market, we include only those traders who submit orders and/or execute trades for contracts with maturity dates within the same month as the transaction occurs.

	Panel A: Spot Market		**Panel B: Futures Market**		**Panel C: Spot and Futures Market**		
Buy & Sell	76,343	70.65%	30,966	86.13%	Spot & Futures	5,362	3.89%
Only Buy	15,317	14.18%	941	2.62%	Only Spot	92,989	67.47%
Only Sell	6,691	6.19%	1,253	3.49%	Only Futures	27,798	20.17%
No Execution	9,701	8.98%	2,791	7.76%	No Execution	11,681	8.47%
Total	108,052	100.00%	35,951	100.00%	Total	137,830	100.00%

Table II Order types

This table shows the number and proportion of new orders, cancellations, and modifications for the spot and futures markets and for buy and sell sides, respectively. Only regular book orders are included in the sample (i.e., we exclude stop-loss orders). For the futures market, we include only those orders for contracts with maturity dates within the same month when the order was submitted / modified / cancelled.

	Panel A: Spot Market				**Panel B: Futures Market**			
	Buy		Sell		Buy		Sell	
New	1,163,764	70.93%	1,173,244	70.59%	649,907	62.46%	642,629	63.13%
Cancel	271,342	16.54%	254,006	15.28%	244,271	23.48%	207,005	20.33%
Modify	205,615	12.53%	234,905	14.13%	146,309	14.06%	168,388	16.54%

Table III Trading volume per trader group

This table shows the number of traders in each trader group, the number of shares bought and sold by each trader group, as well as the total trading volume and proportion of trading volume attributable to each trader group (for traders active on one market only and on both markets). For the futures market, we include only transactions for the contracts with expiry dates within the same month as the transaction occurs. We classify traders into three categories: long-term traders (LTTs), short-term traders (STTs), and small traders (Small). We further split the LTT category into: foriegn instituitions (FIIs), domestic mutual funds (MFs), and other long-termtraders (OLTTs).

Panel A: Spot market

	Active in spot market only					Active on both markets					Grand Total	
	# of traders	Buy	Sell	Total (Buy+Sell)		# of traders	Buy	Sell	Total (Buy+Sell)		(Buy+Sell)	
LTT	1,471	17,578,158	17,764,266	35,342,424	15.6%	219	7,742,075	7,505,290	15,247,365	6.7%	50,589,789	22.3%
FII	107	5,306,538	7,000,068	12,306,606	5.4%	20	1,747,206	1,934,849	3,682,055	1.6%	15,988,661	7.1%
MF	262	2,873,100	5,028,242	7,901,342	3.5%	6	127,500	158,950	286,450	0.1%	8,187,792	3.6%
OLTT	1,102	9,398,520	5,735,956	15,134,476	6.7%	193	5,867,369	5,411,491	11,278,860	5.0%	26,413,336	11.7%
STT	5,597	28,810,041	28,967,762	57,777,803	25.5%	950	40,210,932	40,394,593	80,605,525	35.6%	138,383,328	61.1%
Small	90,646	18,637,725	18,349,047	36,986,772	16.3%	513	225,301	223,274	448,575	0.2%	37,435,347	16.5%
											226,408,464	

Panel B: Futures market

	Active on futures market only					Active on both markets					Grand Total	
	# of traders	Buy	Sell	Total (Buy+Sell)		# of traders	Buy	Sell	Total (Buy+Sell)		(Buy+Sell)	
LTT	6,613	132,127,500	137,226,750	269,354,250	27.5%	219	21,972,750	16,096,500	38,069,250	3.9%	307,423,500	31.3%
FII	40	5,871,000	3,303,750	9,174,750	0.9%	20	7,173,000	2,921,250	10,094,250	1.0%	19,269,000	2.0%
MF	9	668,250	114,000	782,250	0.1%	6	151,500	216,000	367,500	0.0%	1,149,750	0.1%
OLTT	6,564	125,588,250	133,809,000	259,397,250	26.4%	193	14,648,250	12,959,250	27,607,500	2.8%	287,004,750	29.3%
STT	19,574	190,495,500	191,208,750	381,704,250	38.9%	950	139,446,000	139,052,250	278,498,250	28.4%	660,202,500	67.3%
Small	5,628	5,896,500	6,310,500	12,207,000	1.2%	513	635,250	678,750	1,314,000	0.1%	13,521,000	1.4%
											981,147,000	

Table IV Trading activity

This table shows the average daily trading volume between different categories. For the futures market, we include only transactions for the contracts with expiry dates within the same month as the transaction occurs. We classify traders into three categories: long-term traders (LTTs), short-term traders (STTs), and small traders (Small). Daily averages are reported in 100,000 shares.

	Spot Market		Futures Market	
LTT with LTT	1.45	6.8%	8.47	10.2%
LTT with STT	5.64	26.4%	34.41	41.6%
LTT with Small	1.00	4.7%	0.67	0.8%
STT with STT	7.92	37.1%	37.59	45.4%
STT with Small	4.64	21.7%	1.59	1.9%
Small with Small	0.71	3.3%	0.01	0.0%
Total	21.36	100.0%	82.74	100.0%

Table V Trading activity regression during fast crashes

This table shows the average daily trading volume between different trader categories and the results of the trading activity regression estimation based on one-minute intervals from 16-May-2006 till 25-May-2006 for the spot (Panel A) and futures (Panel B) markets. We regress one-minute trading volume relative to the total daily volume between different trader categories in a particular interval on a set of all possible trader-pair dummy variables. We differentiate between buying and selling volumes (see equation (2)). We also include interaction with down/up dummy variables defined as -/+ 30 minutes from the trough of the crash. We estimate regression without a constant. We use day and time fixed effects. We cluster standard errors by day. ***, **, * denotes significance level at 1%, 5%, and 10%, respectively. t-stats are reported in parentheses. " Down=Up" column contains F-stats and respective p-values for the test of equality of the coefficients during drawdown and recovery periods. We classify traders into three categories: long-term traders (LTTs), short-term traders (STTs), and small traders (Small). Daily averages are reported in 100,000 shares. Regression coefficients are reported in basis points.

		Panel A: Spot market					**Panel B: Futures market**				
Sell	Buy	Mean	Normal	Down	Up	Down=Up	Mean	Normal	Down	Up	Down=Up
LTT	LTT	2.233	3.006***	-0.050	7.305***	48.88	11.207	5.069***	-1.283**	3.287	5.4
			(4.64)	(-0.09)	(6.68)	[0.00]		(8.97)	(-2.52)	(1.65)	[0.06]
LTT	STT	3.295	4.464***	5.341**	5.821	0.01	16.061	6.950***	3.902***	2.153	1.65
			(8.73)	(3.22)	(1.24)	[0.94]		(22.60)	(17.84)	(1.42)	[0.25]
LTT	Small	0.604	1.582***	1.548*	1.290*	2.26	0.223	0.940**	-0.251	0.492	14.04
			(5.46)	(2.48)	(2.04)	[0.19]		(2.99)	(-0.58)	(0.96)	[0.01]
STT	LTT	3.082	4.381***	0.580	7.813**	8.42	18.421	7.832***	0.493	6.252**	3.01
			(7.16)	(0.67)	(3.95)	[0.03]		(21.40)	(0.42)	(2.84)	[0.13]
STT	STT	9.143	11.527***	5.873*	2.631	0.85	28.849	11.541***	4.226	2.139	0.21
			(10.76)	(2.12)	(1.79)	[0.40]		(30.45)	(1.48)	(1.17)	[0.67]
STT	Small	2.472	3.897***	2.257*	1.772	5.08	0.510	1.030**	-0.146	0.674	13.25
			(7.32)	(2.04)	(1.50)	[0.07]		(3.16)	(-0.32)	(1.16)	[0.01]
Small	LTT	0.534	1.510***	-0.062	2.554	3.4	0.482	1.079***	-0.147	0.600	6.72
			(5.01)	(-0.13)	(1.54)	[0.13]		(3.83)	(-0.39)	(1.03)	[0.04]
Small	STT	2.508	4.033***	0.763	0.612	0.16	0.954	1.259***	0.657	0.766	0.31
			(8.47)	(0.71)	(0.86)	[0.71]		(4.87)	(0.99)	(1.21)	[0.6]
Small	Small	0.743	1.825***	0.619	1.012	2.9	0.006	0.862**	-0.310	0.381	12.19
			(5.22)	(0.87)	(1.27)	[0.15]		(2.87)	(-0.81)	(0.82)	[0.01]
Day FE				Yes					Yes		
Time FE				Yes					Yes		
Cluster SE				By Day					By Day		
Normalize				By Day					By Day		
Observations				17,289					20,259		
Adjusted R2				0.358					0.449		

Table VI Inventory sensitivity to price movements during fast crashes

This table shows the results of the inventory-sensitivity regression estimation based on one-minute intervals from 16-May-2006 till 25-May-2006 for the spot (Panel A) and futures (Panel B) markets (see equation (5)). We regress changes in inventory in the spot market for STTs, FIIs, and MFs on concurrent return and control variables omitted for brevity (lagged spot/futures inventory, lagged changes in spot/futures inventory). We also include interaction with down/up dummy variables defined as -/+ 30 minutes from the trough of the crash. For the futures inventory computation, we use only transactions for the contracts with expiry dates within the same month as the transaction occurs. We use day fixed effects. We use robust standard errors. ***, **, * denotes significance level at 1%, 5%, and 10%, respectively. We classify traders into three categories: long-term traders (LTTs), short-term traders (STTs), and small traders (Small).

Panel A: Spot market

	STT			FII	MF
	STT -All	STT-Spot	STT-Both		
Spot Return	69.02**	-80.72***	138.08***	93.78***	24.36
	(2.07)	(-3.00)	(3.99)	(3.27)	(1.00)
Down*Spot Return	-274.02**	69.91	-346.47***	294.02*	31.52
	(-2.53)	(1.32)	(-3.33)	(1.81)	(0.55)
Up*Spot Return	-111.07**	87.46**	-174.03***	-55.02	-28.11
	(-2.50)	(2.25)	(-2.86)	(-1.18)	(-0.52)
Down	3.26**	1.16	1.58**	-0.36	3.08*
	(2.44)	(0.88)	(2.35)	(-0.53)	(1.93)
Up	-0.35	-0.36	0.09	-8.44***	3.61
	(-0.33)	(-0.36)	(0.13)	(-2.82)	(1.13)
Constant	-0.57	0.24	-0.50*	0.06	-0.09
	(-1.63)	(1.05)	(-1.92)	(0.37)	(-0.62)
Observations	1,909	1,909	1,909	1,909	1,909
Adjusted R2	0.162	0.089	0.108	0.319	0.186

Panel B: Futures market

	STT			FII	MF
	STT-All	STT-Futures	STT-Both		
Futures Return	-235.59**	42.38	-316.23***	134.98***	-19.58
	(-2.44)	(0.61)	(-5.71)	(3.12)	(-0.55)
Down*Futures Return	161.79	-109.11	278.69**	-228.72***	23.59
	(0.63)	(-0.48)	(2.06)	(-3.13)	(0.64)
Up*Futures Return	3.38	-96.71	206.40**	-233.58*	39.53
	(0.02)	(-1.00)	(2.54)	(-1.83)	(0.99)
Down	5.95**	2.76**	3.32**	-0.25	-0.20
	(1.99)	(2.57)	(2.25)	(-0.57)	(-1.46)
Up	-3.76**	0.76	-2.38*	2.37	0.49
	(-2.19)	(0.71)	(-1.71)	(1.52)	(1.37)
Constant	-0.98	-1.28**	0.15	1.29***	-0.06
	(-1.22)	(-2.23)	(0.31)	(3.04)	(-0.56)
Observations	1,909	1,909	1,909	1,909	1,909
Adjusted R2	0.099	0.068	0.111	0.280	0.292
Day FE	Yes	Yes	Yes	Yes	Yes
Time FE	Yes	Yes	Yes	Yes	Yes
Robust SE	Yes	Yes	Yes	Yes	Yes

Table VII Cash flow regression for STTs during fast crashes

This table shows the results of the cash flow regression estimation based on one-minute intervals from 16-May-2006 till 25-May-2006 for the spot (Panel A) and futures (Panel B) markets. We regress cumulative one-minute cash flows for STTs on crash and recovery dummy variables defined as -/+ 30 minutes from the trough of the crash (see equation (6)). We use day and time fixed effects. We cluster standard errors by day. ***, **, * denotes significance level at 1%, 5%, and 10%, respectively. t-stats are reported in parentheses. For the futures market, we use only transactions for the contracts with maturity dates within the same month as the transaction occurs. We classify traders into three categories: long-term traders (LTTs), short-term traders (STTs), and small traders (Small).

	Panel A: Spot market		Panel B: Futures market	
	(1)	(2)	(1)	(2)
Down	-0.269	-0.241	-2.089	-2.289
	(-0.94)	(-0.71)	(-1.81)	(-1.77)
Up	0.296	0.300	2.486	2.446
	(1.19)	(1.35)	(1.10)	(1.03)
Constant	-0.029	-0.093	0.352*	0.545
	(-0.65)	(-0.59)	(2.37)	(1.07)
Day FE	No	Yes	No	Yes
Time FE	No	Yes	No	Yes
Cluster SE	By Day	By Day	By Day	By Day
Observations	1,562	1,562	1,562	1,562
Adjusted R2	0.002	-0.000	0.015	0.016

Table VIII Activity of traders during the two crash days: Spot market

This table shows the activity of traders during the two crash days in the spot market. We document the number of active traders; buy and sell volume for the crash, recovery, and normal periods during either May 19, 2006 or May 22, 2006; and also the trading volume on other days in our sample for the traders active on the crash days. Crash/recovery periods are measured as -/+30 minutes from the trough of the crash. We split all active traders on the crash days based on their activity during the crash periods.

Active during crash	# of traders	May 19 and May 22, 2006						Other days	
		Crash		Recovery		Normal		Normal	
		Buy	Sell	Buy	Sell	Buy	Sell	Buy	Sell
Panel A: FII									
All	9	-	142,177	-	185,457	15,000	322,597	497,817	537,155
No	4	-	-	-	-	15,000	117,825	334,095	185,850
Yes	5	-	142,177	-	185,457	-	204,772	163,722	351,305
Panel B: MF									
All	23	64,880	1,429	220,132	22,590	293,506	57,250	83,214	150,250
No	18	-	-	48,820	22,590	197,698	55,500	26,000	114,500
Yes	5	64,880	1,429	171,312	-	95,808	1,750	57,214	35,750
Panel C: OLTT									
All	218	60,516	77,438	178,833	184,164	580,937	479,794	4,965,863	4,415,356
No	158	-	-	153,088	94,827	416,086	170,945	1,622,123	1,367,612
Yes	60	60,516	77,438	25,745	89,337	164,851	308,849	3,343,740	3,047,744
Panel D: STT									
All	1,099	482,888	436,390	462,004	473,347	2,468,184	2,535,794	47,166,445	47,416,618
No	636	-	-	76,555	73,874	637,397	651,622	10,769,273	10,942,637
Yes	463	482,888	436,390	385,449	399,473	1,830,787	1,884,172	36,397,172	36,473,981
Panel E: Small									
All	12,038	150,320	101,170	117,760	113,171	636,518	598,710	4,599,521	4,576,813
No	8,723	-	-	70,336	42,170	413,719	372,067	2,624,039	2,610,454
Yes	3,315	150,320	101,170	47,424	71,001	222,799	226,643	1,975,482	1,966,359
Total	13,387	758,604	758,604	978,729	978,729	3,994,145	3,994,145	57,312,860	57,096,192

Table IX Activity of traders during the two crash days: Futures market

This table shows the activity of traders during the two crash days in the futures market. We document the number of active traders; buy and sell volume for the crash, recovery, and normal periods during either May 19, 2006 or May 22, 2006; and also the trading volume of the traders active on the crash days on other days in our sample. Crash/recovery periods are measured as -/+30 minutes from the trough of the crash. We split all active traders on the crash days based on their activity during the crash periods.

Active during crash	# of traders	May 19 and May 22, 2006						Other days	
		Crash		Recovery		Normal		Normal	
		Buy	Sell	Buy	Sell	Buy	Sell	Buy	Sell
Panel A: FII									
All	11	63,750	6,000	244,500	58,500	291,750	27,750	3,918,750	1,767,750
No	5	-	-	99,000	47,250	129,000	750	1,672,500	1,108,500
Yes	6	63,750	6,000	145,500	11,250	162,750	27,000	2,246,250	659,250
Panel B: MF									
All	5	-	-	32,250	-	499,500	-	41,250	67,500
No	5	-	-	32,250	-	499,500	-	41,250	67,500
Yes	0	-	-	-	-	-	-	-	-
Panel C: OLTT									
All	1231	450,000	631,500	711,750	629,250	3,819,750	3,980,250	67,514,250	68,700,750
No	897	-	-	429,000	350,250	2,448,750	2,405,250	39,138,750	41,028,000
Yes	334	450,000	631,500	282,750	279,000	1,371,000	1,575,000	28,375,500	27,672,750
Panel D: STT									
All	1530	1,208,250	1,031,250	1,046,250	1,314,750	7,023,000	7,457,250	203,295,000	202,553,250
No	1032	-	-	201,000	204,000	1,618,500	1,916,250	51,138,750	50,891,250
Yes	498	1,208,250	1,031,250	845,250	1,110,750	5,404,500	5,541,000	152,156,250	151,662,000
Panel E: Small									
All	624	21,000	74,250	28,500	60,750	99,000	267,750	1,060,500	773,250
No	506	-	-	27,000	56,250	90,000	256,500	851,250	625,500
Yes	118	21,000	74,250	1,500	4,500	9,000	11,250	209,250	147,750
Total	3401	1,743,000	1,743,000	2,063,250	2,063,250	11,733,000	11,733,000	275,829,750	273,862,500

Table X Quality of LTTs' trade execution

This table shows the regression for the terms of execution faced by LTTs as compared to STTs and Small traders (see equation (7)) separately for buy and sell volume. As a dependent variable, we use the volume-weighted average price for each trader relative to the volume-weighted average price for all traders during the day. We further split the LTT category into: foreign institutions (FIIs), domestic mutual funds (MFs), and other long-term traders (OLTTs). Active is a dummy variable that equals one if a trader was active during 19 and/or 22 of May 2006. We use day fixed effects. We cluster standard errors by day and trader. ***, **, * denotes significance level at 1%, 5%, and 10%, respectively. *t*-stats are reported in parentheses.

	Panel A: Spot market				**Panel B: Futures market**			
	Buy		Sell		Buy		Sell	
	(1)	(2)	(3)	(4)	(1)	(2)	(3)	(4)
FII	0.11	0.06	-0.34***	-0.31***	-0.21***	-0.30***	-0.04	0.16
	(0.95)	(0.43)	(-3.60)	(-2.77)	(-2.73)	(-3.08)	(-0.25)	(1.09)
MF	-0.26**	-0.22*	-0.12	-0.07	-0.92***	-0.74***	-0.23	-0.29
	(-2.00)	(-1.82)	(-1.19)	(-0.71)	(-2.73)	(-2.68)	(-0.95)	(-1.06)
OLTT	-0.18**	-0.14*	-0.04	-0.02	-0.06**	-0.03	-0.02	-0.02
	(-2.35)	(-1.86)	(-1.01)	(-0.47)	(-2.32)	(-0.84)	(-1.20)	(-0.67)
FII*Active		0.27**		-0.23		0.23*		-0.59**
		(2.04)		(-0.88)		(1.89)		(-2.10)
MF*Active		-0.16		-0.34		-0.70		0.31
		(-0.30)		(-1.28)		(-0.68)		(1.07)
OLTT*Active		-0.08		-0.06		-0.06		-0.01
		(-0.91)		(-0.82)		(-1.52)		(-0.37)
Active		-0.09***		-0.02		-0.08***		-0.01
		(-4.51)		(-1.43)		(-3.47)		(-0.57)
Constant	99.99***	100.01***	100.05***	100.05***	99.99***	100.00***	100.09***	100.09***
	(57,540.45)	(23,668.04)	(117,955.45)	(36,376.13)	(14,102.95)	(10,952.60)	(21,242.53)	(17,034.93)
Observations	265,362	265,362	254,224	254,224	119,550	119,550	123,559	123,559
Adjusted R2	0.018	0.019	0.031	0.031	0.010	0.011	0.010	0.010
Day FE	Yes				Yes			
Clustered SE	By Trader and Day				By Trader and Day			

Table XI Granger-causality

This table shows the results of the Granger-causality tests for a vector-autoregression for one-minute returns and marketable order imbalances from different trader categories (see equation (9)) for the spot (Panel A) and futures (Panel B) markets. Panel C shows the Granger-causality tests for a vector-autoregression for one-minute returns in the spot and the futures markets (see equation (10)). We estimate vector-autoregression for the crash days and for the four non-crash days. We classify traders into three categories: long-term traders (LTTs), short-term traders (STTs), and small traders (Small). We further split the LTT category into: foreign institutions (FIIs), domestic mutual funds (MFs), and other long-term traders (OLTTs). For brevity, we report only those Granger causality tests that are relevant for our analysis.

	19-22 of May			16-25 of May, excl crash days			
Equation	Excluded	Chi2	p-value	Equation	Excluded	Chi2	p-value
Panel A: Spot market							
Ret	MOIB FII	2.921	0.087	Ret	MOIB FII	0.806	0.369
Ret	MOIB MF	10.321	0.001	Ret	MOIB MF	0.110	0.740
MOIB FII	Ret	0.080	0.777	MOIB FII	Ret	0.811	0.368
MOIB FII	MOIB MF	1.249	0.264	MOIB FII	MOIB MF	0.045	0.833
MOIB MF	Ret	2.541	0.111	MOIB MF	Ret	1.331	0.249
MOIB MF	MOIB FII	0.060	0.806	MOIB MF	MOIB FII	1.180	0.277
Panel B: Futures market							
Ret	MOIB FII	0.048	0.827	Ret	MOIB FII	2.936	0.087
Ret	MOIB MF	1.307	0.253	Ret	MOIB MF	0.133	0.715
MOIB FII	Ret	4.333	0.037	MOIB FII	Ret	0.292	0.589
MOIB FII	MOIB MF	0.295	0.587	MOIB FII	MOIB MF	0.889	0.346
MOIB MF	Ret	0.563	0.453	MOIB MF	Ret	0.526	0.468
MOIB MF	MOIB FII	0.038	0.846	MOIB MF	MOIB FII	0.003	0.956
Panel C: Spot and Futures markets							
Ret Spot	Ret Fut	9.95	0.00	Ret Spot	Ret Fut	235.92	0.00
Ret Fut	Ret Spot	15.26	0.00	Ret Fut	Ret Spot	1.30	0.52

Figure 1. Trader Classification

This figure shows the trader classification scheme used in this paper.

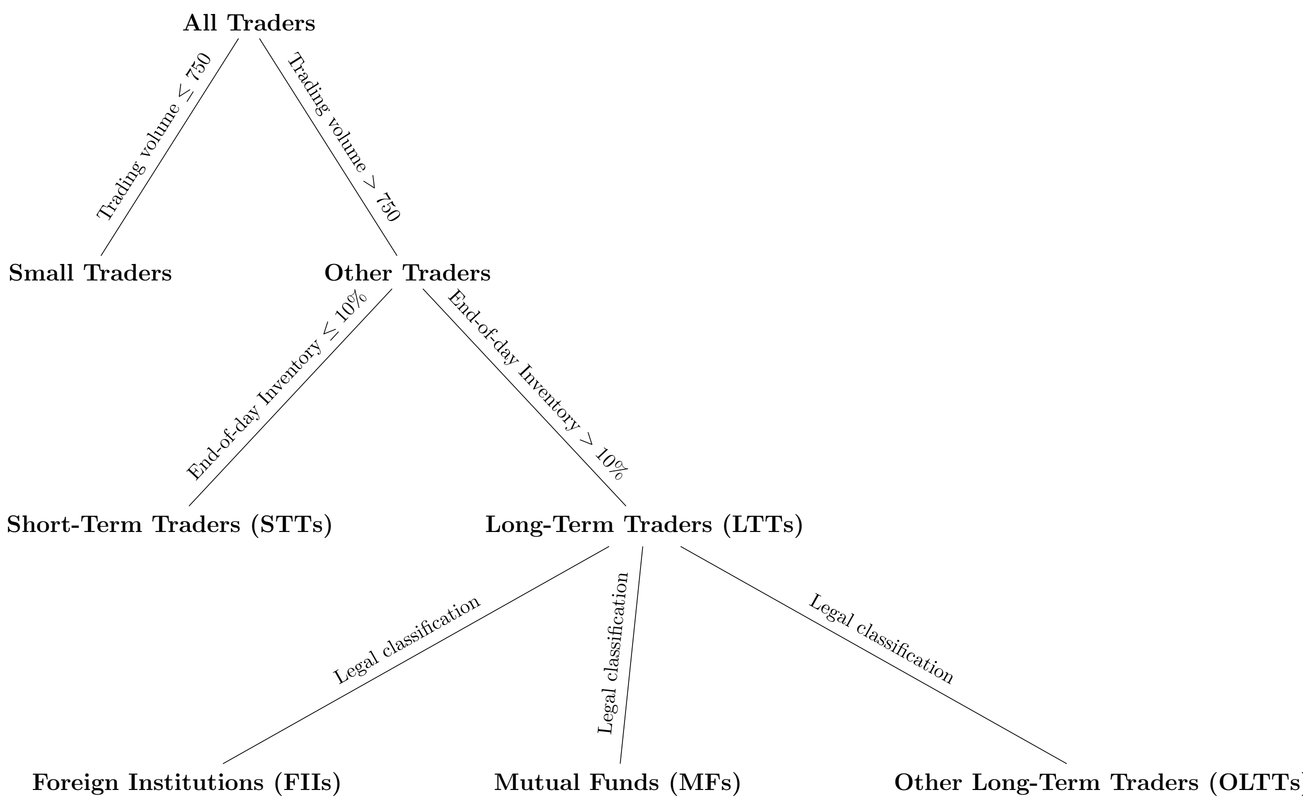


Figure 2. Fast crashes

This figure shows the dynamics of the mid-quote in the spot and futures markets, together with NIFTY prices at a one-minute frequency for the two fast crash days: May 19 and May 22, 2006. Mid-quotes and prices are scaled to 100 at the beginning of the trading day.

Panel A: 19th of May 2006 Panel B: 22nd of May 2006

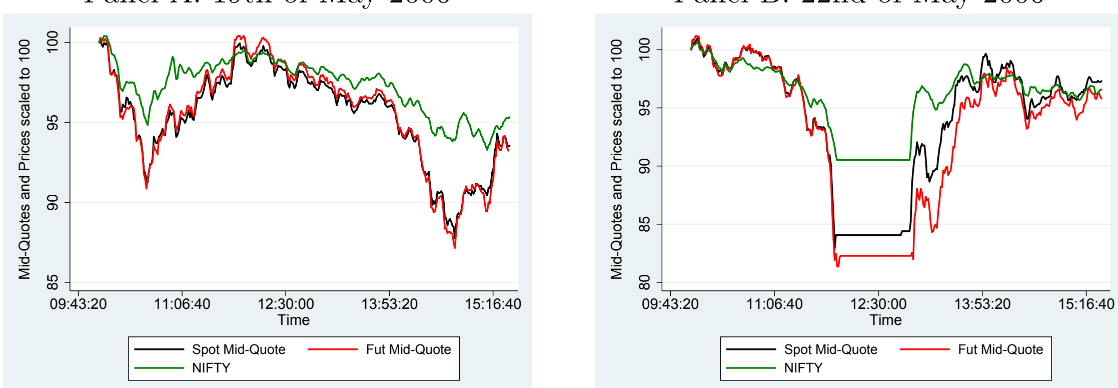
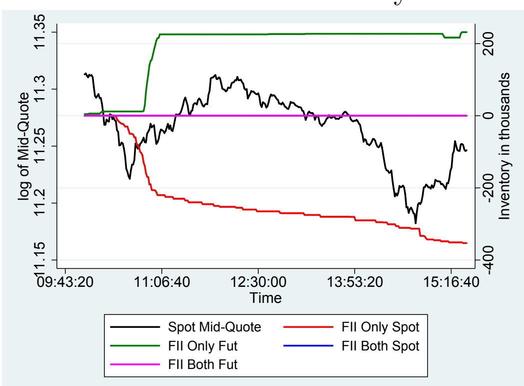


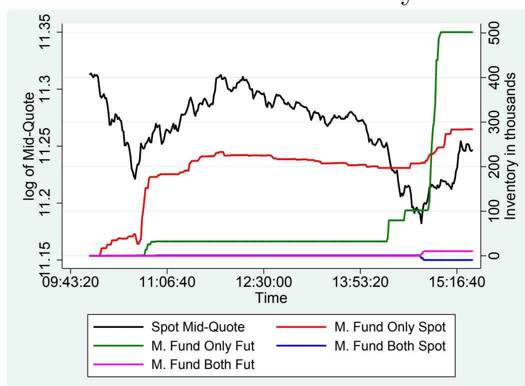
Figure 3. Inventory dynamics for FIIs and MFs during the fast crashes

This figure shows dynamics of the mid-quote and inventory of FIIs and MFs at a one-minute frequency for the spot and futures markets during the two fast crash days: May 19 and May 22, 2006.

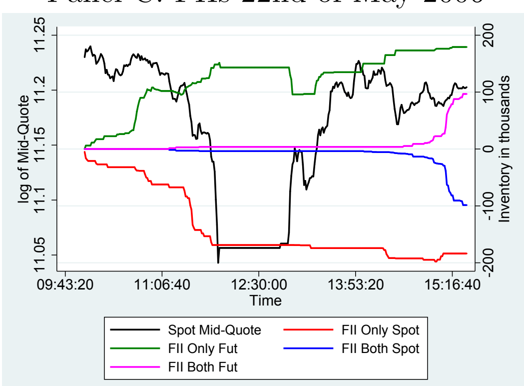
Panel A: FIIs 19th of May 2006



Panel B: MFs 19th of May 2006



Panel C: FIIs 22nd of May 2006



Panel D: MFs 22nd of May 2006

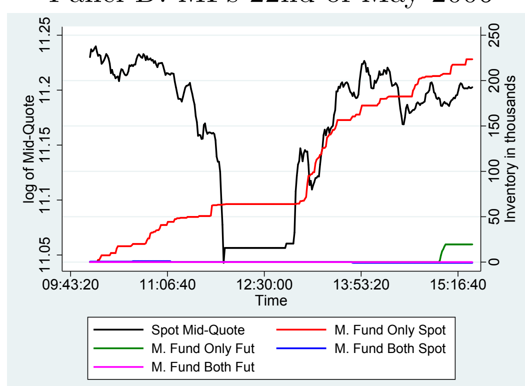
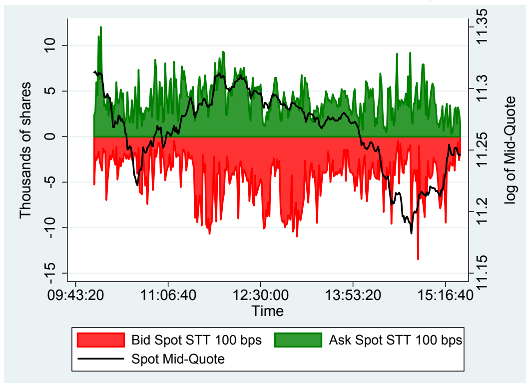


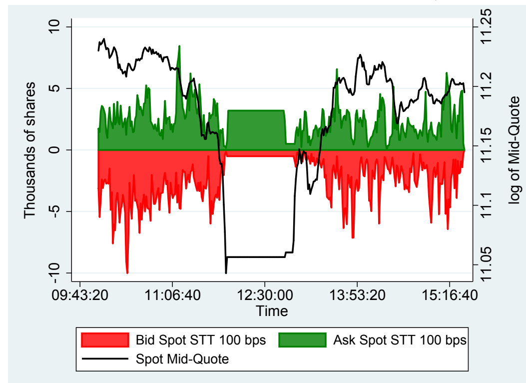
Figure 4. Depth of the limit order book during the fast crashes: Spot market

This figure shows the median number of shares outstanding within 100 bps from the midpoint for STTs, FIIs, and MFs, respectively, at a one-minute frequency for the spot market during the two fast crash days: May 19 and May 22, 2006.

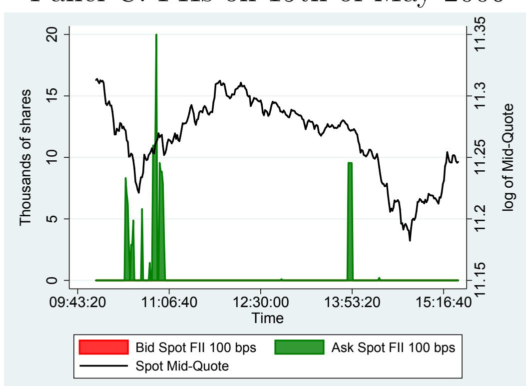
Panel A: STTs on 19th of May 2006



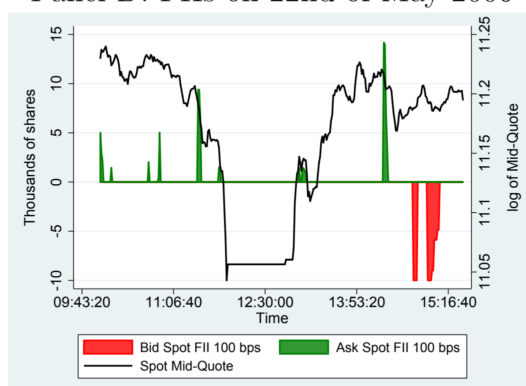
Panel B: STTs on 22nd of May 2006



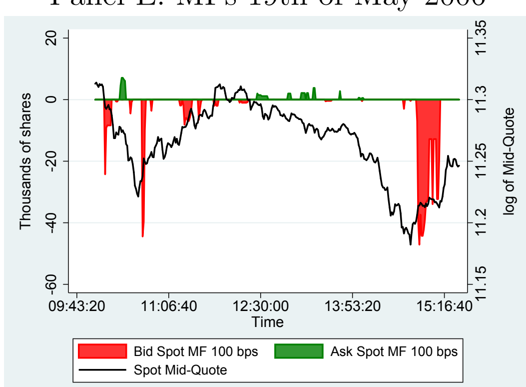
Panel C: FIIs on 19th of May 2006



Panel D: FIIs on 22nd of May 2006



Panel E: MFs 19th of May 2006



Panel F: MFs 22nd of May 2006

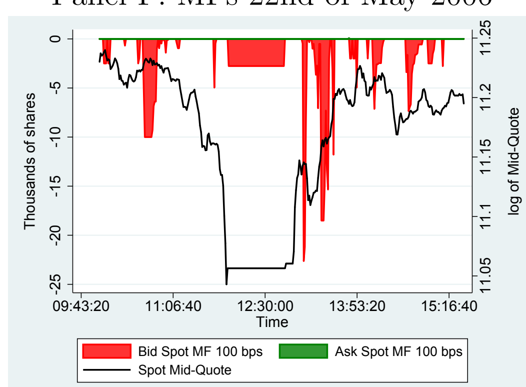
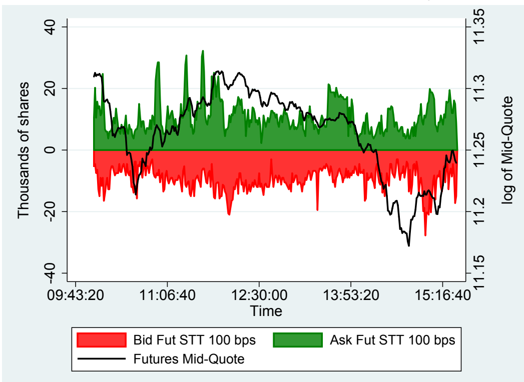


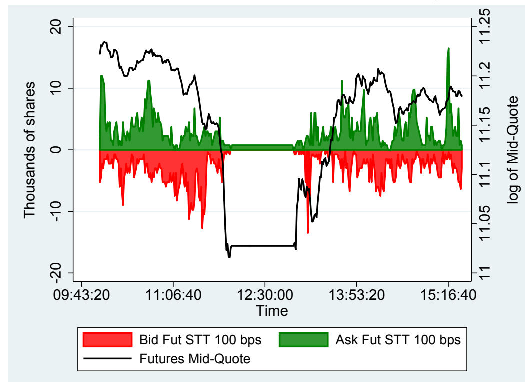
Figure 5. Depth of the limit order book during the fast crashes: Futures market

This figure shows the median number of shares outstanding within 100 bps from the midpoint for STTs, FIIs, and MFs, respectively, at a one-minute frequency for the futures market during the two fast crash days: May 19 and May 22, 2006.

Panel A: STTs on 19th of May 2006

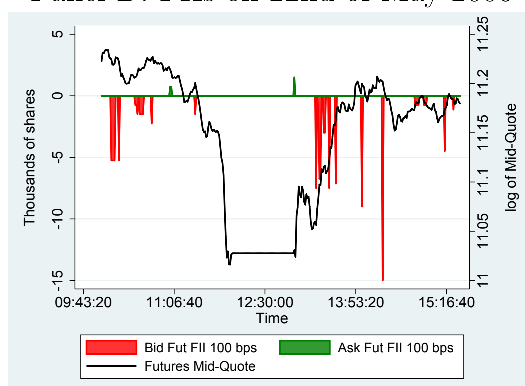


Panel B: STTs on 22nd of May 2006

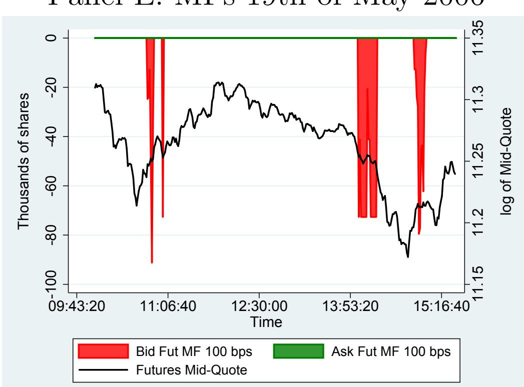


Panel C: FIIs on 19th of May 2006

Panel D: FIIs on 22nd of May 2006



Panel E: MFs 19th of May 2006



Panel F: MFs 22nd of May 2006

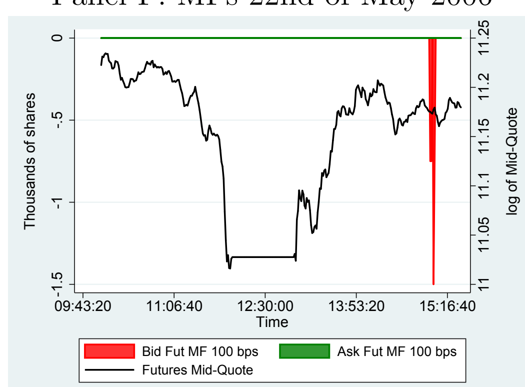


Figure 6. Arbitrage proxies

This figure shows the dynamics of the two proxies for arbitrage opportunities (see Menkveld and Yueshen (2018)) and the mid-quote (median over one minute) during the two fast crash days: May 19 and May 22, 2006.

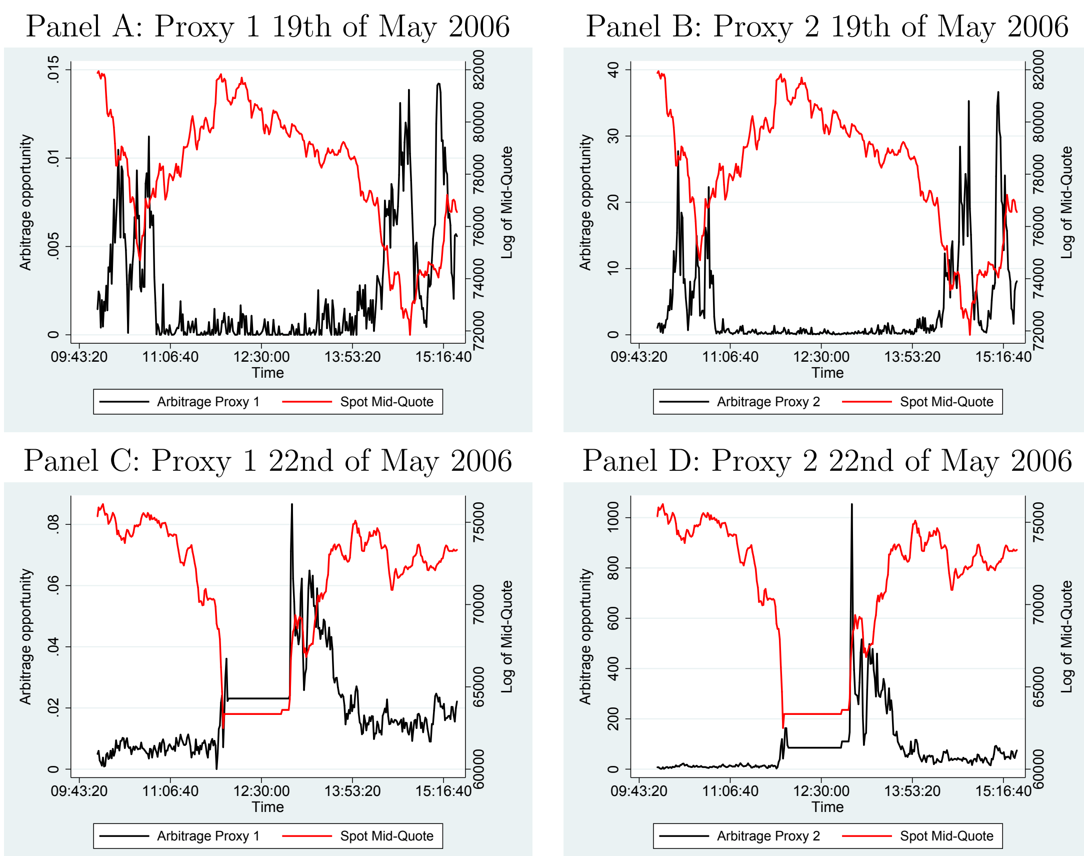
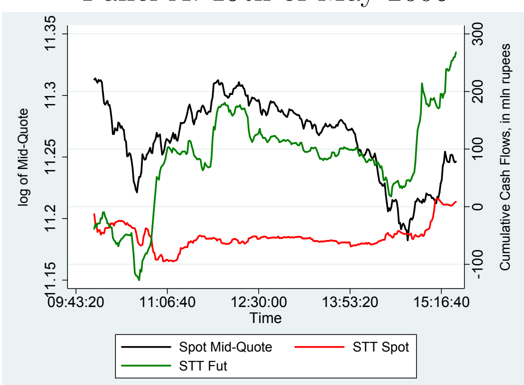


Figure 7. Cumulative cash flows of STTs during the fast crashes

This figure shows cumulative cash flows of STTs at a one-minute frequency for the spot and futures markets during the two fast crash days: May 19 and May 22, 2006. Cumulative cash flows are computed as the cumulative sum of + (−) price times the number of shares traded in case of sell (buy) transaction.

Panel A: 19th of May 2006



Panel B: 22nd of May 2006

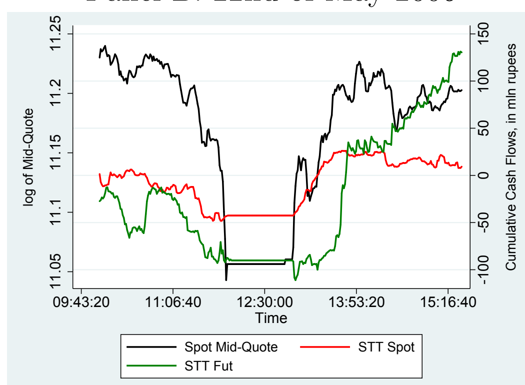


Figure 8. Activity of STTs during the two crash days

This figure shows shows the activity of STTs during the two crash days in our sample. We document the number of active traders for the crash, recovery, and normal periods during either May 19, 2006, or May 22, 2006, for the spot (futures) markets. Crash/recovery periods are measured as -/+30 minutes from the trough of the crash. We split all active STTs on the crash days based on their activity during the crash periods, whether they belong to the most active STTs (STTs that generate 50% of total volume), and whether they were constrained during the crash days (their maximum one-minute inventory was above 95% percentile of the maximum inventories on non-crash days).

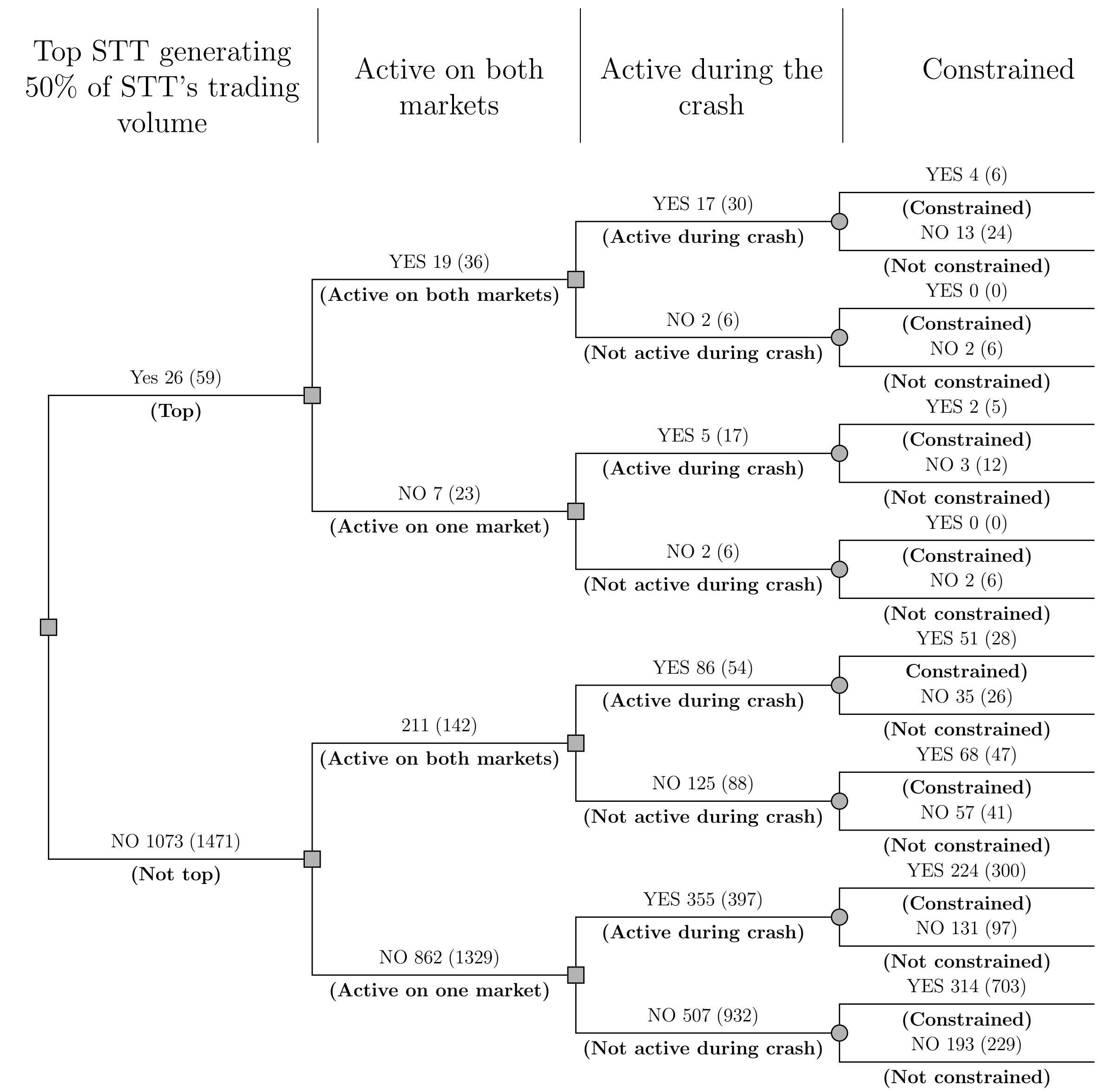
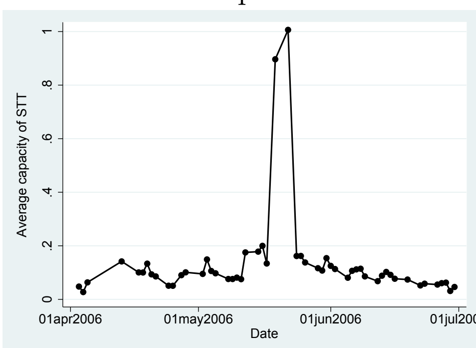


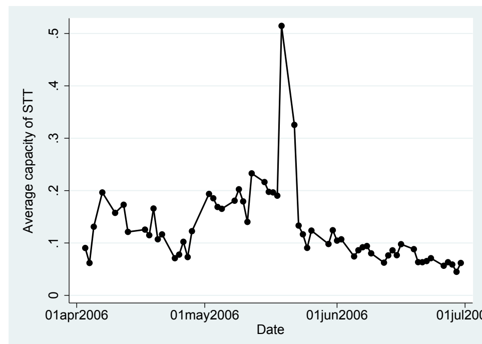
Figure 9. Inventory capacity of STTs

This figure shows the average STTs capacity. Panels A and B show the maximum absolute value of one-minute median inventory positions during the day relative to the maximum absolute inventory position in our sample period excluding two crash days (May 19 and May 22, 2006) for the spot and futures markets, respectively. Panels C and D (Panels E and F) show the absolute value of one-minute median inventory positions relative to the maximum absolute inventory position in our sample period excluding two crash days (May 19 and May 22, 2006) for the spot and futures markets, respectively, for May 19 (22), 2006.

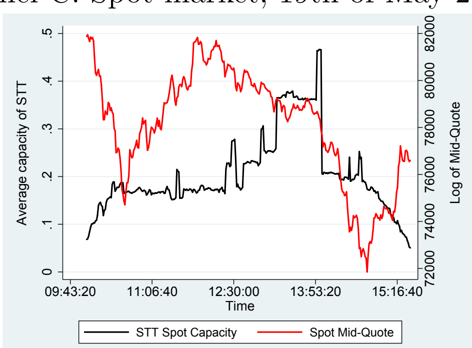
Panel A: Spot market



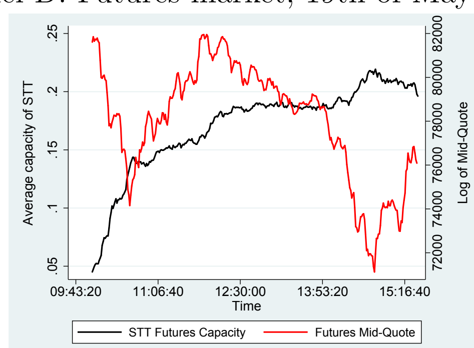
Panel B: Futures market



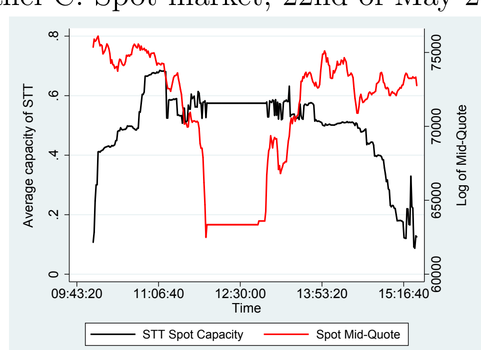
Panel C: Spot market, 19th of May 2006



Panel D: Futures market, 19th of May 2006



Panel C: Spot market, 22nd of May 2006



Panel D: Futures market, 22nd of May 2006

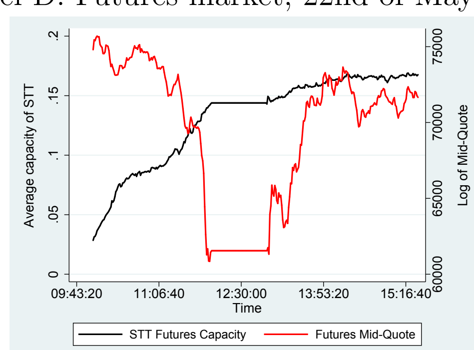
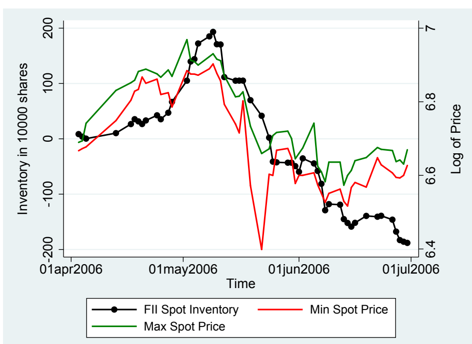


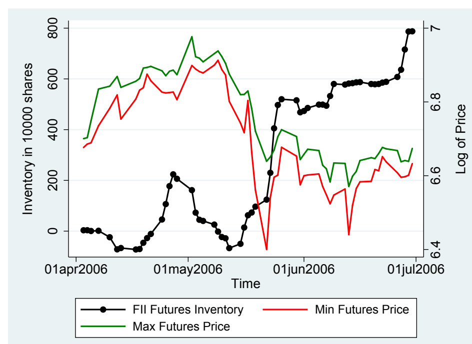
Figure 10. Cumulative inventories of FIIs

This figure shows the cumulative end-of-day inventory position of FIIs in the spot and futures markets. Panels A and B show the cumulative end-of-day inventory position of all FIIs in our sample, while Panels C and D show the cumulative end-of-day inventory position of FIIs that were active on the two crash days: May 19 and May 22, 2006. Negative values of cumulative inventories should be interpreted as a decrease of the starting position as of the beginning of April 2006.

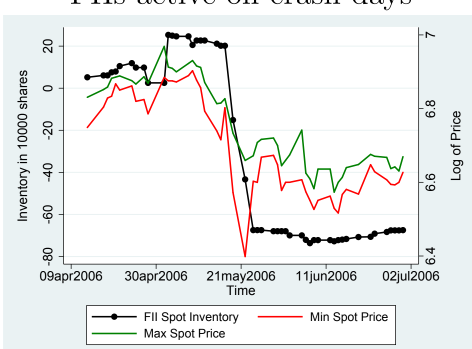
Panel A: Spot market:
all FIIs



Panel B: Futures market:
all FIIs



Panel C: Spot market:
FIIs active on crash days



Panel D: Futures market:
FIIs active on crash days

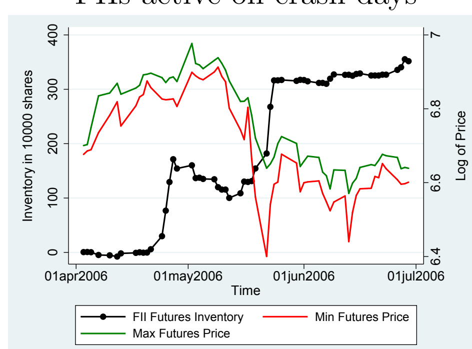
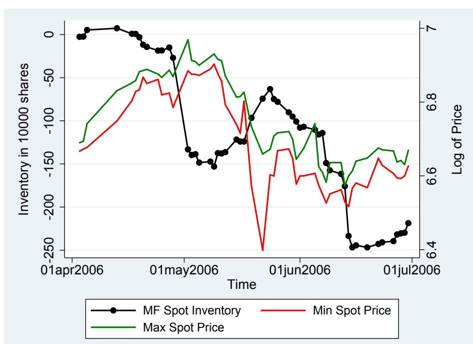


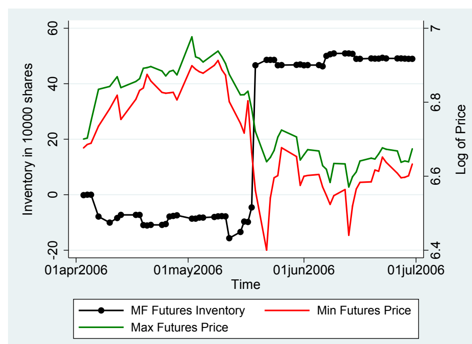
Figure 11. Cumulative inventories of MFs

This figure shows the cumulative end-of-day inventory position of MFs in the spot and futures markets. Panels A and B show the cumulative end-of-day inventory position of all MFs in our sample, while Panels C and D show the cumulative end-of-day inventory position of MFs that were active on the two crash days: May 19 and May 22, 2006. Negative values of cumulative inventories should be interpreted as a decrease of the starting position as of the beginning of April 2006.

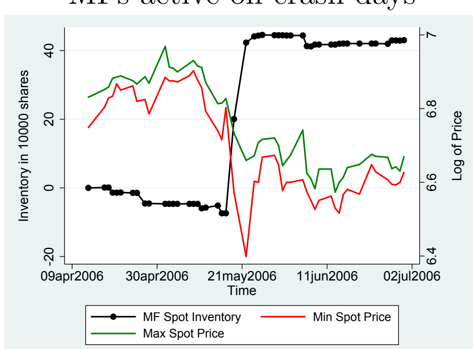
Panel A: Spot market:
all MFs



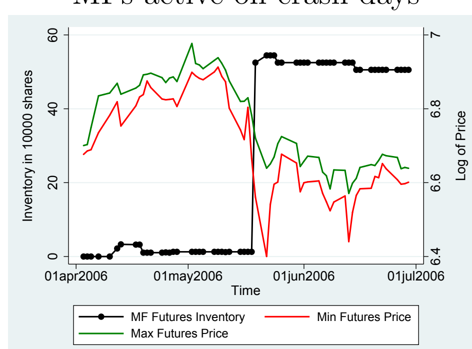
Panel B: Futures market:
all MFs



Panel C: Spot market
MFs active on crash days



Panel D: Futures market
MFs active on crash days



Appendix A Description of the National Stock Exchange (NSE)

The National Stock Exchange (NSE) of India Ltd. was incorporated in November 1992, following the liberalization of the Indian financial market and the official establishment of the Securities and Exchange Board of India in 1992. The process of financial liberalization has supported the development of a large group of stock exchanges in India. The NSE and the Bombay Stock Exchange (BSE) are the largest stock exchanges in the country based on market capitalization and traded volume, though there are a total of 21 exchanges that actively operate in India. 97.71% (55.99%) of stocks are traded daily on the NSE (BSE). In 2011, the market capitalization of stocks traded on the NSE was Rs. 67 trillion (USD 1.5 trillion) while the total market capitalization of stocks traded on the BSE was Rs. 68 trillion (USD 1.5 trillion).

The NSE is a fully automated screen-based platform that works through an electronic limit order book in which orders are timestamped and numbered and then matched on price and time priority. The NSE requires all traders to submit their orders through certified brokers who are solely entitled to trade on the platform. These brokers are trading members with exclusive rights to trade, and they can trade on their own account (proprietary trades) or on behalf of clients. Brokers can trade in equities, derivatives, and debt segments of the market. The number of active trading members has greatly grown from 940 members in 2005 to 1,373 members in 2012. Most of them trade in all segments of the market. Every day, more than two million traders actively trade on the platform through several trading terminals located throughout India. While there are no designated market-makers on the NSE, a small group of de facto market-makers typically control a large portion of trading.

Futures contracts have been trading on the NSE since November 2001. These futures contracts have a three-month trading cycle, with each contract trading for three months until expiration. Every month, a new contract is issued. So, at any point of time for a given underlying stock, there are three futures contracts being traded.

INSERT FIGURE A1 HERE

In 2006, trading sessions for both stock and futures markets were between 9:55 a.m. and 15:30 p.m., with a closing session of 20 minutes from 15:40 p.m. till 16:00 p.m. only for the spot market. Figure A1 show the trading day timeline in more details.

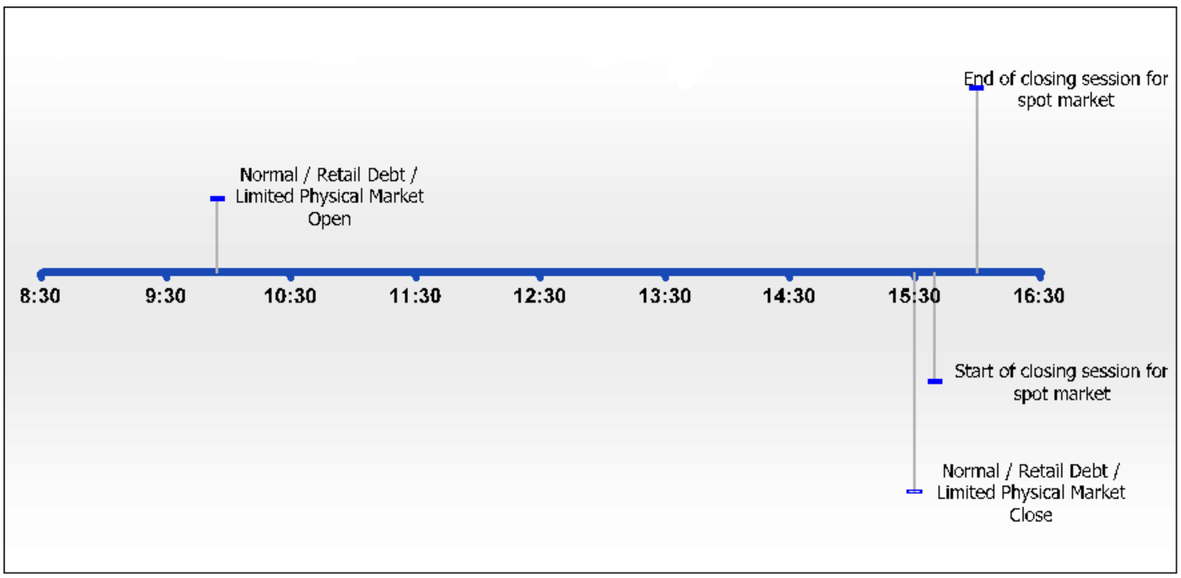
Appendix B Persistence of STTs

On a given day, we classify traders into Small traders, long-term traders (LTTs), and short-term traders (STTs). To determine the final category of a trader, we look at the mode of the classification of traders across days and select it as a trader category if the mode is not equal to “Small” trader. If a mode classification is equal to “Small” trader, we assign it as a trader category if and only if a trader is classified as Small trader on more than two-thirds of days; otherwise, we use the next most frequent classification as the trader’s category. The main focus of our analysis are STTs. Hence, we look at how persistent this trader category is. Table B1 shows the proportion of active days on which STTs were classified as STTs. We look separately at the STTs that represent jointly 75% and 50% of the trading volume of this category (i.e., the most active STTs).

INSERT TABLE B1 HERE

Figure A1. Trading day timeline

This figure shows the trading day timeline of the National Stock Exchange of India (NSE) as of 2006.



Time	Event
9:55	Normal / Retail Debt / Limited Physical Market Open
15:30	Normal / Retail Debt / Limited Physical Market Close
15:40	Start of closing session for spot market
16:00	End of closing session for spot market

Table B1 STTs' persistence

This table shows summary statistics (number of traders, average number of active days, 5%, 50%, and 95% percentile of persistence ratio) for STTs in the spot and futures markets. We define persistence ratio as a proportion of all active days when a trader is classified as an STT. We present these statistics for all STTs, top STTs responsible jointly for 75% of STTs' trading volume, and top STTs responsible jointly for 50% of STTs' trading volume.

	Panel A: Spot market					**Panel B: Futures market**				
	# of traders	# of active days	P5	P50	P95	# of traders	# of active days	P5	P50	P95
All STT	6,547	5.31	33%	71%	100%	20,524	4.38	33%	100%	100%
75% STT	289	26.44	44%	79%	100%	596	27.61	52%	86%	100%
50% STT	27	46.56	60%	81%	100%	64	50.06	65%	92%	100%