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Liquidity provision: Normal times vs Crashes

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ABSTRACT

We study the role of various trader types in providing liquidity in spot and futures markets based on data 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 liquidity providers in both spot and futures markets. We have two crashes in our sample, both originated in the spot market and spilled into the futures market. Mutual funds had to move in before price recovery took place in both markets. Market stability may require the presence of well-capitalized standby liquidity providers for recovery from crashes.

JEL classification: G12, G14.

Keywords: Liquidity Provision; Market Fragility; Flash Crash; Slow-Moving Capital.

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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 exchanges' and regulators' attention on the need to better understand liquidity provision in the stock and futures markets. In this paper, we show that the primary providers of liquidity during crashes and normal times are different.

We show that traders who carry little end-of-day inventory (short-term traders, or STTs) are the primary providers of liquidity during normal times, with no distinction between the spot and the futures markets. 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 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 move in only after prices have dropped sufficiently, highlighting the slow-moving feature of standby market-making capital.[1] 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 and SENSEX indexes traded on the National Stock Exchange of India (NSE).[2] 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.

[1] Another potential reason for the slow-moving nature of MFs' intermediation capital could be that a sharp drop in a stock's price draws MFs' attention, after which MFs 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.

[2] 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.

Our data have the following advantages. First, the data have a unique identifier for each broker-trader combination for spot and futures markets, which allows us to calculate the evolution of individual traders' inventory over time. Second, the data have the legal classification (Mutual Fund (MF), Foreign Institutional Investor (FII), and so on) 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.[3]

In this study, we go beyond the legal classification of traders and identify short-term traders (STTs) and long-term traders (LTTs) directly based on their trading behavior. STTs tolerate deviations from their desired inventory positions only for short periods of time. 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 measure liquidity provision during normal times by trader categories in the following ways: contribution to the depth outstanding on both sides of the limit order book; the market-making index (the balance between passive buying and passive selling volume);[4] and centrality in the trading network.

However, the above-mentioned measures of liquidity provision are not fully suitable during crashes for the following reasons. First, during crashes, the limit order book changes fast; therefore the book at a point in time is much less informative than during normal times.

[3]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.

[4]We use the market-making index as in Comerton-Forde, Malinova, and Park (2018) and Korajczyk and Murphy (2019).

Second, during crashes, those who provide liquidity will be buying rather than selling; during normal times, those who make a market will be both buying and selling, and thus the market-making index will look different during crashes and normal times. Therefore, we measure the liquidity provision by trader categories during crashes based on the trading volume in the opposite direction of the price decline.

We find that STTs, who carry relatively small amounts of intraday inventory relative to their trading volume and little inventory overnight (less than 10% of their daily trading volume), are central to the trading network. In particular, top STTs, who are jointly responsible for 50% of STTs' trading volume, have 46 (17) times more counterparties than the next-most-connected category (FIIs) in the spot (futures) market. We document that STTs are the main liquidity providers, as they contribute more than 50% of the depth outstanding in the limit order book up to 100 basis points from the mid-quote for the spot and futures markets alike. Further, STTs are balanced in terms of their market-making activity, both as a category and at the individual trader level, especially the top STTs, which have an overall market-making index lower than 10%. To sum up, we show that STTs are the main transaction hub as well as the main liquidity providers during normal times for both the spot and futures markets.

There were two crashes and recoveries in both the spot and futures markets alongside stock market indices such as NIFTY and SENSEX. The first (second) crash was characterized by a drop in the spot market mid-quote by 7.9% (10.2%) within 30 minutes, followed by a sharp recovery of more than 60% within the 30 minutes after the crash's trough.

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, which 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 the 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 and selling at better prices than other traders on average. 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.[5]

To summarize, we provide a comprehensive analysis of the roles of STTs, some of whom trade in both spot and futures markets, and slow-moving standby liquidity providers during normal times, 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 liquidity provision by STTs during normal times. Section V characterizes liquidity provision by STTs and standby liquidity providers during the two crashes in our sample. We conclude in Section VI.

I. Related literature

There is some consensus in the recent literature that high-frequency traders (HFTs) are the main liquidity providers during normal times. Hendershott, Jones, and Menkveld (2011) show that an increase in automation leads to an increase in liquidity provision. Menkveld (2013) focuses on a single cross-venue HFT and documents that, in four out of five trades,

[5]Note that crash-day causality measures the average effect during the entire crash day. The market drawdown period is too short to estimate causality during that period alone.

the trader was providing liquidity. Malinova, Park, and Riordan (2018) show that retail traders enjoy better liquidity due to HFTs' activity. In our sample period, there are no HFTs.[6] STTs (who, like current day HFTs, had limited inventory-carrying capacity and ended up mostly flat at the end of the day) are the main liquidity providers during normal times, consistent with the above literature.

The focus of the recent literature on crashes has been on whether HFTs were instrumental in initiating and accentuating the crashes. 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 from the market of many liquidity providers – most of whom were HFTs. 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). In addition to the studies on the role of HFTs in crashes, 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.

The above-mentioned papers focus on identifying why crashes occurred and on understanding the role HFTs and arbitrageurs play in this process. In our paper, we find that large selling by FIIs initiated both crashes, and buying by MFs stabilized the market and helped it recover from the crashes, despite MFs having been slow to move in. 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.

[6]High-frequency trading, and algorithmic trading in general, was not allowed at the NSE during our sample period.

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 NSE, which provides us with a unique identifier for each broker-trader combination and legal classification in the spot and futures markets.[7] Our data includes detailed information on trades and quotes (the full history of the order: submission, modification, cancellation, and execution). All our subsequent analysis is conducted for this one representative NSE stock.[8] We exclude three days with half-day trading sessions from our sample (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 the period under consideration. 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 (91.53%). The majority of the active traders on either the spot (70.65%) or futures (86.13%) markets execute their orders on both sides of the market (i.e., they both buy and sell). 67.47% of traders execute their orders in the spot market only, while 20.17% of traders execute their orders on the 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

[7]Kahraman and Tookes (2017) and Murphy and Thirumalai (2017) also use data provided by the NSE.
[8]We refer to Appendix A for a detailed description of the NSE market.

modifications (around 13% for the buy side and 14% for the sell side of the market). Similar patterns also hold for the futures market.[9] 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, traders' legal classifications are not adequate for analyzing traders' role in liquidity provision in different 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 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

[9]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)).

one futures contract) on a given day.[10] Other traders' 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. LTTs are traders whose end-of-day inventory is more than 10% of traded volume. We further split LTTs into MFs, FIIs, and other long-term traders (OLTTs). MFs and FIIs are legal entities according to the NSE.[11] To determine a trader's final category, we look at its modal classification 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 it is classified as a Small trader on more than two-thirds of days; otherwise, we use the next most frequent classification as the trader's category.[12] 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).[13]

INSERT TABLE III HERE

Table III shows buy and sell trading volume for each of the three trader categories. In particular, we find that STTs are responsible for 61.1% (67.6%) of the total (buy and sell) trading volume for the spot (futures) market. LTTs are responsible for 22.4% (31.1%) of the total trading volume for the spot (futures) market. Small traders are responsible for 16.5% (1.3%) of the total trading volume for the 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 28.6% for spot and futures markets, respectively, while all other

[10]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 the futures market for hedging purposes.

[11]We note that several MFs and FIIs end up in Small or STT categories. 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.

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

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

trader categories are active mainly in either the spot market or the futures market. We also note that the futures market is five times larger than the spot market, but the spot market is more diverse in terms of market participants.

The size difference between 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 basis points) than for the futures market (around 1 basis points). Moreover, it is easier to take short positions in the futures market than in the spot market. Overnight short positions in the spot market were not allowed during our sample period, except through participatory notes, but this way of borrowing shares was available to very few investors, mainly FIIs.

IV. Liquidity provision during normal times

In this section, we show that STTs are the main liquidity providers during normal times. First, we show that STTs are central to the trading network in both the spot and futures market using a degree centrality measure (i.e., they are the main intermediaries in both markets). Second, we show that STTs have a dominant presence in the limit order book. Third, we show that STTs are balanced in terms of their passive buys and passive sells (market-making index). Finally, we measure the effective costs of STTs' liquidity provision using their average profits per share traded with other trader categories.

A. Trading network

Table IV shows the average degree centrality (i.e., the number of counterparties each individual trader has) across traders per each trader category during the whole trading day, during the first and last 30 minutes and the rest of the trading day. We note that there are more traders active during the rest of the day (4 hours and 30 minutes) than during the first and last 30 minutes of the trading day, as expected from the different duration of the periods under consideration.

INSERT TABLE IV HERE

We document that top STTs (the largest STTs, who are jointly responsible for 50% of STTs' trading volume and are present on almost every day in our sample period) exhibit the highest degree centrality of more than 33,000 (5,000) counterparties on the spot (futures) market during the whole trading day, which is 46 (17) times larger than the amount of counterparties the next-most-connected trader category (FIIs) has. Intraday patterns on spot and futures markets also show that STTs' relative importance in the trading network is lower at the beginning and end of the trading day, with the most profound intraday patterns observed in the spot market. In particular, on the spot market, top STTs have 35 (20) times more connections than FIIs in the first (last) 30 minutes of the trading day, as compared to 42 times during the rest of the trading day. This intraday pattern is in line with the fact that STTs prefer to end their day with flat inventory positions, and thus are less likely to act as intermediaries for other market participants in the first and last 30 minutes of the trading day.

We also note that although MFs have only 155 (67) counterparties during the whole trading day on the spot (futures) market, and thus are not central to the trading network during normal times, we show that their role is crucial during turbulent periods in Section V.B.

INSERT FIGURE 2 HERE

Figure 2 plots the trading network for the spot and futures markets, with vertex's size representing the total trading volume by each trader category and the width of the edges representing the trading activity among the trader categories for the whole trading day. Figure 2 shows that the majority of the trading volume occurs between STTs themselves in both the spot and futures markets. We also show that STTs act as main counterparties for other trader categories in spot and futures markets alike, as depicted by the width of the edges connecting STTs and other trader categories.

Overall, we document that STTs are in the center of the trading network for both spot and futures markets alike during normal times.

B. Contribution to the limit order book depth

While STTs are the main intermediaries in the spot and futures markets, as measured by the degree centrality measure, it does not necessarily follow that STTs are the main liquidity providers in the spot and futures markets. Therefore, we look at STTs' presence at the different price levels of the limit order book, and also in close proximity (in basis points) to the mid-quote.

INSERT TABLE V HERE

Panel A of Table V reports an average of one-minute median depth in thousands of shares outstanding at the different price levels of the limit order book, together with the proportion of shares coming from STTs, where the first level is the best bid-offer level (i.e., the lowest ask price and highest bid price), and the first 3 levels are the three lowest ask prices and three highest bid prices, and so on. We also conduct a t-test as to whether STTs' contribution is significantly different from 50%. In the spot market, STTs' presence at the best bid-offer level equals 66.3% and 68.7% at the bid and ask side, respectively. In the futures markets, STTs' presence at the best bid-offer level equals to 72.9% and 82.7% at the bid and ask side, respectively. STTs' presence decreases while moving to the levels of the limit order book that are further away from the mid-quote. STTs' presence is statistically larger than 50% for the best bid-offer level, as well as the first 3, 5, and 10 levels of the limit order book, except for the first 10 levels in the futures market, where we cannot reject the null of STTs' presence being equal to 50%.

Panel B of Table V reports an average of one-minute median depth in thousands of shares 10, 25, 50, 75, and 100 basis points away from the mid-quote, together with the proportion of shares coming from STTs. We also conduct a t-test as to whether STTs' contribution is significantly different from 50%. In the spot market, STTs supply 58.7% and 58.3% of the total depth within 10 basis points from the mid-quote at the bid and ask side, respectively. In the futures markets, STTs supply 66.5% and 65.9% of the total depth within 10 basis points form the mid-quote at the bid and ask side, respectively. Moving further away from the mid-quote decreases STTs' presence.

Figure 3 depicts STTs' presence in close proximity to the mid-quote for the first 30 minutes, last 30 minutes, and the rest of the trading day. Though the limit order book is thinner at the beginning and the end of the trading day, STTs are consistently present in the close proximity of the mid-quote, followed by OLTTs, while MFs' and FIIs' presence is almost negligible.

INSERT FIGURE 3 HERE

C. Market-making index

We estimate a market-making index (absolute difference between passive buying and passive selling volume relative to passive trading volume) following Comerton-Forde, Malinova, and Park (2018) and Korajczyk and Murphy (2019). A trader engaging in market-making activity should be balanced in terms of its passive execution on both sides of the market. A fully balanced trader's market-making index should be close to zero.

INSERT TABLE VI HERE

Table VI shows the average market-making index for the trader category as a whole, as well as for individual traders within each trader category, for the whole trading day as well as during the first and last 30 minutes and the rest of the trading day separately for spot and futures markets. We show that as a whole, STTs have the smallest market-making index among all categories for both the spot (5.9%) and futures (8.3%) markets for the whole trading day. The respective number for LTTs is 15.9% (9.0%), and for their subsets (namely, FIIs and MFs), the respective number does not fall below 58.0% (81.5%) on the spot (futures) market.

At the individual trader level for STTs, the market-making index is larger than the one for STTs as a whole. We document that top STTs (who are the largest STTs, jointly responsible for 50% of STTs trading volume and are present on almost every day in our sample period) are the ones who exhibit the most pronounced market-maker characteristics with a market-making index of 26.6% (26.8%) for the whole trading day on the spot (futures) market. For comparison, Korajczyk and Murphy (2019) classifies traders as market-makers if their median market-making index is below 20%.

We note that intraday patterns are especially profound for STTs' liquidity provision. Namely, top STTs have a market-making index of 44.5% (46.5%) and 50.7% (50.5%) during the beginning and end of the trading day and 29.0% (29.2%) during the rest of the trading day for the spot (futures) market. Intraday patterns are in line with the fact that STTs tend to start and end their day flat in term of inventory, and therefore are less balanced in terms of trading volume direction in the beginning and end of the trading day. To sum up, our results suggest that STTs (especially top STTs) exhibit market-maker characteristics more than any other trader category.

D. Price of liquidity

We have documented that STTs serve as a hub for the majority of transactions and are the main liquidity providers. In this section, we measure the price of STTs' liquidity provision using their profits. We compute STTs' profits as the difference between selling and buying trading volume in rupees for the STT category as a whole; on average for each trader; and also per share, traded with other trader categories for the whole trading day, the first and last 30 minutes, and the rest of the trading day.[14]

INSERT TABLE VII HERE

We show that STTs as a category make positive profits of more than 7 (21) millions rupees in the spot (futures) market on average per day. We show that STTs make positive profits during the rest of the trading day and the last 30 minutes of the trading day, while losing money during the first 30 minutes of the trading day for both the spot and futures market. This pattern might be explained by the fact that in the beginning of the trading day, STTs need to build up an inventory position because they end their day flat.

We measure the cost of STTs' liquidity provision as profits per share traded with other trader categories during the whole trading day. We document that profits per share are equal to 4.90 (7.70) rupees as compared to the average quoted spread in our sample of 0.45 (0.73) rupees for the spot (futures) market. These numbers translate to 58.40 (90.98) basis points per share and 5.4 (8.6) basis points, respectively. We note that STTs' profits on the spot market are not statistically significant, indicating high profit volatility.

V. Liquidity provision during crashes

In this section, we identify stock price crashes and study different trader categories' liquidity provision during crashes.

A. Identification of the crashes

We identify crashes using two methods, both of which identify essentially the same crashes. First, we use the drift-burst statistics developed by Christensen, Oomen, and Renò (2016) and also used by Bellia, Christensen, Kolokolov, Pelizzon, and Renò (2018):

[14] STTs' profits are very volatile; therefore, we winsorize the profits at the 5% and 95% level.

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

Intuitively, the drift-burst statistic compares the average one-minute mid-quote returns, r_t, computed over the rolling window before time t (with the length of the window determined by the bandwidth, h_μ) to the volatility of the returns computed over the rolling window before time t (with the length of the window determined by the bandwidth, h_σ), with the most recent observations receiving the highest weight. A crash trough is the time t when the average returns become too large with respect to their volatility. 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 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 crash troughs. The critical value used in the paper accounts for the multiple tests, as in Christensen, Oomen, and Renò (2016).[15] In our sample, we detect eight

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

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 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.

Second, we use the more intuitive crash identification rule: a 3% drop in one-minute mid-quotes over 15 minutes on both the spot and futures markets, followed by a recovery in one-minute mid-quotes of 3% over 15 minutes on both markets. We obtain the same two crashes with the trough point of May 19 being exactly the same as identified by the drift-burst statistic, and the trough point for May 22 being two minutes later than the one identified by the drift-burst statistic. Since the two crashes' troughs that the two methods identified are essentially the same, we use the troughs identified by the first method (the drift-burst statistic) for the analysis that follows.

For further analysis, we focus our attention on the four days surrounding the crash days from May 16 through May 25.[16] We compare liquidity provision during the crash days with liquidity provision during the two days before and two days after the crash instead of comparing with all other days in the sample.

INSERT FIGURE 4 HERE

Figure 4 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 on which the crashes happened. On May 19, we observe two events that look like a 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.

[16]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 day.

During the 30 minutes before the first crash's trough, prices fell by 7.9% and recovered by only 5.1% (reversal of 64.5%) in the 30 minutes that followed. However, during the 30 minutes before the second crash's trough, prices 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 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% (a 68.4% reversal). This 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 crashes were accompanied by similar movement in the NIFTY index, though it was less pronounced.

B. Liquidity provision during crashes

B.1. Trading network

Table VIII shows the average degree centrality (i.e., number of counterparties each individual trader has) across traders per each trader category during crashes and recovery defined as +/- 30 minutes from the crash's trough for the bidirectional network as well as a split between buy and sell networks.

INSERT TABLE VIII HERE

We document that contrary to normal times (see Table IV), top STTs (the largest STTs, jointly responsible for 50% of STTs' trading volume and present on almost every day in our sample period) do not stand out in terms of the number of counterparties during crashes and recoveries. In particular, during crashes, the number of counterparties top STTs have is equal to the number of counterpaties FIIs have on the spot market and is only two times larger on the futures markets, as opposed to 46 (spot market) and 17 (futures market) times during normal periods. During recoveries, tops STTs are at par with FIIs in terms of number of counterparties on the spot market, and they lose their leading position to FIIs on the futures market.

Splitting up the bidirectional network into buy and sell networks yields interesting results. Namely, we show that while STTs remain relatively balanced during both crashes and recoveries on the spot and futures markets alike, FIIs and MFs tend to be present only on one side of the network. In particular, on the spot market, FIIs (MFs) are present only on the sell (buy) network, consistent with FIIs generating large selling pressure, leading to a crash. On the futures market, both FIIs and MFs tend to be present on the buy network only.

B.2. Contribution to the limit order book depth

To provide further evidence on STTs' liquidity provision during crashes, we look at the limit order book and plot the number of shares quoted in close proximity to the mid-quote from 30 to 20 minutes before the crash's trough, from 20 to 10 minutes before the crash's trough, and from 10 minutes before the crash's trough and from the crash's trough to 10 minutes after it, from 10 to 20 minutes after the crash's trough of the crash, and from 20 minutes to 30 minutes after the crash's trough (see Figures 7 – 8) for the spot and futures markets, respectively.

INSERT FIGURES 7 – 8 HERE

During crashes, STTs are present on both sides of the limit order book for the spot and futures market alike. In the spot market, we document that STTs do not change their presence during the lifespan of the crash on both crash days, May 19 and May 22, 2006. In the futures market, both STTs decrease their presence in the close proximity to the mid-quote on the bid side of the limit order book; however, STTs never quote less on the bid side then on the ask side of the limit order book.

The main changes in the limit order book during crashes come from LTTs' behavior. In particular, during the first 10 minutes of the crash, MFs quote considerable depth on the buy side of the limit order book, switching to the sell side of the book as the crash evolves and coming back to the bid side of the book in the last 10 minutes before the trough in the spot market. OLTTs come to the buy side of the limit order book only in the last 10 minutes before the crash, while FIIs consistently quote depth on the sell side of the limit order book in the spot market. In the futures market, MFs and FIIs are barely present in the limit order book during the crash period on both sides of the market and OLTTs come to the limit order book in the last 10 minutes of the crash similar to the spot market.

During the recovery, STTs are also present on both sides of the market; however, MFs and OLTTs have the dominant presence on the buy side of the limit order book. We observe that MFs come to the buy side of the limit order book immediately after the trough in the spot market, while it takes longer for them to move in the futures market. We note that during normal times, MFs' and FIIs' contribution to the depth outstanding in the limit order book is negligible (see Figure 3).

B.3. Market-making index

We estimate a market-making index (absolute difference between passive buying and passive selling volume relative to passive trading volume) for crashes and recoveries defined as -/+ 30 minutes from the crash's trough.

INSERT TABLE IX HERE

Table IX shows the average market-making index for the trader category as a whole, as well as for individual traders within each trader category, for crashes and recoveries for both the spot and futures markets.

During crashes, STTs as a category have a market-making index of 17.5% (19.3%), as opposed to 5.9% (8.3%) during normal times for the spot (futures) market (see Table VI).

At the individual trader level, top STTs have a market-making index of 40.7% (46.4%), as opposed to 26.6% (26.8%) during normal times for the spot (futures) market (see Table VI). Recoveries exhibit similar patterns.

This results suggest that STTs become less balanced in terms of their passive buys and sells during turbulent times. The market-making index for other trader categories remained largely unchanged.

B.4. Trading behavior

As discussed before, measures of liquidity provision during normal times might not be fully suitable to examine liquidity provision during crashes, which can be viewed as trading against the price movement no matter whether trading volume is passive or aggressive. We investigate trader behavior by looking at the trading volume between the different categories during the two 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 drawdown ($Down_{kt}$) and recovery (Up_{kt}) periods, day fixed effects (FE_k), and half-hour time dummies (TD_b). More formally:

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

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

Table X shows the results of the trading-activity regression estimation around the two crashes in our sample (May 19, 2006, and May 22, 2006) for spot and futures markets.

INSERT TABLE X HERE

Panel A of Table X 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 crash was similar to their buying from LTTs during the recovery period. In summary, STTs tried to accommodate the volume LTTs sold, 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 X shows that during market recovery after the 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 X repeats the analysis discussed above for the futures market. During drawdown periods, STTs increased 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 decreased 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.

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 FIIs' and MFs' activity on the crash days.

Unfortunately, we cannot estimate equation (2) by enriching it with FII and MF categories due to multicollinearity problems: FII activity is concentrated during the drawdown period and MF activity is concentrated during the recovery period; however, we also provide graphical representation of MFs' and FIIs' behavior (see Figure 5). Figure 5 shows that FIIs' selling in the spot market coincides with the crashes (see Panels A and C), while MFs' buying 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 the spot and futures markets; however, these positions are established by different traders within the FII category, so they are not driven by cross-market arbitrage activity. We provide a more detailed analysis on MFs' and FIIs' role in Section V.D.

INSERT FIGURE 5 HERE

Figure 5 suggests that the crashes were driven by selling pressure from FIIs in the spot market, while FIIs' behavior 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, they 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 compared to normal periods. 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 crash and zero otherwise.

INSERT TABLE XI HERE

In Table XI, we document the estimation results of equation (5). The first column reports the sensitivity of STTs' as a whole (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 whole, 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 categories: STT-Spot, STT-Futures, and STT-Both.

The second column of Panel A of Table XI 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 V.C.2, we investigate this issue in depth.

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

The third column of Table XI 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 – that is, STT-Both are taking opposite positions in the 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 (i.e., STT-Both did not seem to engage in cross-market arbitrage activities during

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

the crashes), and thus cross-market arbitrage broke down during the crashes.

The analysis performed following Kirilenko, Kyle, Samadi, and Tuzun (2017) considers STTs as a whole 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 V.C.

Table XI also reports FIIs' and MFs' inventory sensitivity. 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, MFs do not change their inventories as frequently as one-minute changes in returns. Thus, we do not find any significant coefficients for MFs, and we provide a more detailed analysis on the role of both FIIs and MFs in Section V.D.

C. The role of STTs during crashes

In this section, we argue that STTs could not prevent 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 V.C.1). Second, we show that STTs indeed were inventory constrained during the crash days (see Section V.C.2).

C.1. STTs' cash flows

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 drawdown ($Down_{kt}$) 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 crash's trough and zero otherwise.

INSERT TABLE XII HERE

Table XII shows the results of the cash flow regression estimation around the two crashes in our sample (on May 19, 2006, and May 22, 2006) for the spot and futures markets. Panels A and B of Table XII 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 STTs' cumulative cash flows during the two crash days (Figure 9). We find that STTs' cumulative cash flows decrease during market drawdowns and increase during recovery periods.

INSERT FIGURE 9 HERE

C.2. STTs' inventory capacity

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 the dynamics of STTs' inventory capacity at daily and intraday levels (the latter for the two crash days only).

INSERT FIGURE 10

Figure 10 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 categories based on whether they belong to the top category 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 trader's 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 category, 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 category of STTs participated during the market drawdown, with 27% of them hitting their inventory constraints. Out of the smaller STT category, 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 category, 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. In particular, many STTs hit their inventory constraints and withdraw from the market.

Figure 11 plots a 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 11 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.

Most traders have exhausted their inventory capacity during the crash days. We now zoom in and show the dynamics of STTs' inventory capacity at the intraday level. 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 11 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 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, and therefore negative inventories in the spot market should be interpreted as a decrease of the starting inventory position.

INSERT FIGURE 12 – 13 HERE

Panel A of Figures 12 – 13 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

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

down and sell when the price goes up. Panel B of Figures 12 – 13 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 13 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 until 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 XIII and XIV provide summary statistics for different trader categories' participation 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 XIII). 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 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 XIII 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 XIV provides summary statistics for FIIs' and MFs' participation in the futures market during the crash days. Panels A and B of Table XIV 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 XIV show that the behavior of OLTTs and STTs in the futures market is similar to their behavior in the spot market.

INSERT TABLES XIII – XIV HERE

In Figures 12 – 13, we showed that MFs in the spot and futures markets and FIIs in the futures market systematically act as opportunistic traders. Multiple reasons could give rise to such trading patterns, and in the following analysis, we test one possible explanation. 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) STTs' volume-weighted price (i.e., there should be a 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

[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.

dummy variable that equals one for traders active the crash days, the interaction between them, and day fixed effects (FE_k):[20]

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

INSERT TABLE XV HERE

Panel A of Table XV shows that, for the specification, including interaction variables, 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 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 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 XV 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 move slowly not because they are slow to react to the market signal, but because they wait until the price hits their buying limit estimate from the "fair-value" model.

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

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 categories. We use BIC criterion to decide on the number of lags, n. We compute the marketable order imbalance for each trader category i as a ratio of buy volume initiated by trader category i minus sell volume initiated by this trader category 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]

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

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

Panels A and B of Table XVI 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

[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.

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' nor MFs' marketable order imbalance 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 different traders' combined behavior 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 XVI reports a 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 heavy selling pressure from FIIs occurred only in the spot market, while both markets experienced crashes.

VI. Conclusion

Stock price crashes, though infrequent, do occur with adverse consequences. The Flash Crash of May 6, 2010, has drawn regulators' and exchanges' attention to the need to understand the role of different types of traders during crashes and their recoveries as opposed to normal periods.

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 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. Traders active on both markets are mainly STTs. We find that STTs are the major liquidity providers in both the spot and futures markets: they are central in the trading network; they contribute to a large share of the depth outstanding on both sides of the limit order book in the proximity to the best bid-offer level; and they are balanced in terms of their passive buys and sells. MFs are patient traders that trade much less than STTs, but with better execution quality. In line with the previous literature indicating that 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 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 prices Granger-caused changes in spot prices. 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 (five times) higher trading volume than spot. However, both 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 MFs, which 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 (STTs) being the de facto liquidity providers. As such, our findings suggest that 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 the 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 as the order was submitted, modified, or 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 category

This table shows the number of traders in each trader category, the number of shares bought and sold by each trader category, as well as the total trading volume and proportion of trading volume attributable to each trader category (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: foreign institutions (FIIs), domestic mutual funds (MFs), and other long-term traders (OLTTs).

Panel A: Spot market

	Active on 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	17,357,955	17,336,561	34,694,516	15.7%	219	7,622,099	7,260,429	14,882,528	6.7%	49,577,044	22.4%
FII	107	5,273,086	6,891,532	12,164,618	5.5%	20	1,746,656	1,934,157	3,680,813	1.7%	15,845,431	7.2%
MF	262	2,823,229	5,024,574	7,847,803	3.6%	6	124,500	158,950	283,450	0.1%	8,131,253	3.7%
OLTT	1,102	9,261,640	5,420,455	14,682,095	6.6%	193	5,750,943	5,167,322	10,918,265	4.9%	25,600,360	11.6%
STT	5,597	27,945,058	28,262,521	56,207,579	25.4%	950	39,287,510	39,373,997	78,661,507	35.6%	134,869,086	61.1%
Small	90,646	18,018,051	17,995,050	36,013,101	16.3%	513	213,797	215,912	429,709	0.2%	36,442,810	16.5%
											220,888,940	100.0%

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	127,703,250	131,735,250	259,438,500	27.2%	219	21,497,250	15,598,500	37,095,750	3.9%	296,534,250	31.1%
FII	40	5,710,500	3,239,250	8,949,750	0.9%	20	7,121,250	2,894,250	10,015,500	1.0%	18,965,250	2.0%
MF	9	664,500	114,000	778,500	0.1%	6	150,750	214,500	365,250	0.0%	1,143,750	0.1%
OLTT	6,564	121,328,250	128,382,000	249,710,250	26.2%	193	14,225,250	12,489,750	26,715,000	2.8%	276,425,250	29.0%
STT	19,574	185,267,250	186,960,000	372,227,250	39.0%	950	136,363,500	136,211,250	272,574,750	28.6%	644,802,000	67.6%
Small	5,628	5,644,500	5,949,000	11,593,500	1.2%	513	614,250	636,000	1,250,250	0.1%	12,843,750	1.3%
											954,180,000	100.0%

Table IV Trading network

This table shows the average degree centrality measure (number of counterparties) of bidirectional trading network (both buys and sells) for each trading category for spot (Panel A) and futures (Panel B) markets, respectively. We compute the degree centrality measure for the whole trading day, for the first and last 30 minutes of the trading day, and the rest of the trading day. For the futures market, we include only transactions for the contracts with an expiry date 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 foreign institutions (FIIs), domestic mutual funds (MFs), and other long-term traders (OLTTs). We further split the STT category into the largest STTs (STT Top), who jointly generate 50% of STT trading volume, and small STTs (STT Not Top).

	Panel A: Spot market				**Panel B: Futures market**			
	Total	First 30 minutes	The rest of the trading day	Last 30 minutes	Total	First 30 minutes	The rest of the trading day	Last 30 minutes
LTT	210	57	175	75	44	9	33	10
FII	713	111	602	164	291	52	244	42
MF	155	61	134	92	67	19	59	25
OLTT	171	50	138	62	42	9	31	10
STT	292	60	233	52	37	10	29	10
STT Not Top	156	30	124	31	20	5	16	6
STT Top	33,051	3,952	25,806	3,292	5,104	678	3,796	631
Small	14	4	11	4	3	1	2	1

Table V Contribution to the limit order book depth

This table shows liquidity provision by STTs as measured by their contribution to the depth outstanding in the limit order book. Panel A shows the average of one-minute median depth and the proportion of the depth from STTs at the different price levels of the limit order book. Panel B shows the average of one-minute median depth and the proportion of the depth from STTs in proximity (in basis points, bps) to the mid-quote. We also report t-stats of the t-test whether the proportion of average depth provided by STTs is equal to 50% in parentheses. ***, **, and * denote significance level at 1%, 5%, and 10%, respectively. Average depth is reported in 1,000 shares. We classify traders into three categories: long-term traders (LTTs), short-term traders (STTs), and small traders (Small).

Panel A: STT presence in the limit order book

	Spot market				Futures market			
	Bid side		Ask side		Bid side		Ask side	
# of LOB levels	Average depth	% from STT	Average depth	% from STT	Average depth	% from STT	Average depth	% from STT
1 level	0.40	66.3%***	0.40	68.7%***	1.43	72.9%***	1.01	82.7%***
		(49.57)		(58.88)		(13.70)		(24.27)
First 3 levels	1.47	66.3%***	1.43	67.2%***	6.04	58.1%***	4.59	62.5%***
		(69.54)		(74.72)		(6.17)		(12.19)
First 5 levels	2.45	65.2%***	2.33	65.1%***	10.33	53.5%***	8.28	56.9%***
		(71.31)		(72.98)		(2.85)		(7.30)
First 10 levels	4.42	62.3%***	4.33	60.7%***	18.57	49.1%	17.43	50.2%
		(65.61)		(58.34)		(-0.82)		(0.30)

Panel B: STT presence in the proximity of the midpoint

	Spot market				Futures market			
	Bid side		Ask side		Bid side		Ask side	
# of bps from the midpoint	Average depth	% from STT	Average depth	% from STT	Average depth	% from STT	Average depth	% from STT
10	1.92	58.7%***	1.82	58.3%***	3.88	66.5%***	4.28	65.9%***
		(37.43)		(35.29)		(72.12)		(69.25)
25	5.08	59.8%***	5.03	57.8%***	11.09	64.8%***	13.68	63.0%***
		(52.81)		(42.29)		(87.39)		(74.76)
50	9.89	56.0%***	10.55	53.3%***	22.88	61.8%***	34.40	59.3%***
		(38.27)		(21.74)		(81.52)		(64.24)
75	14.15	53.6%***	16.52	50.7%***	34.26	60.0%***	58.94	57.2%***
		(25.34)		(5.23)		(75.63)		(55.70)
100	17.90	51.6%***	22.08	49.0%***	44.51	58.6%***	85.53	55.4%***
		(12.07)		(-7.99)		(69.66)		(45.27)

Table VI Market-making index

This table shows liquidity provision by trader categories as measured by market-making index ($\frac{|Passive\ buy\ volume - Passive\ sell\ volume|}{Passive\ buy\ volume + Passive\ sell\ volume}$). We report the market-making index for a trader category as a whole as well as on average for traders within each trader category for the spot (Panel A) and futures (Panel B) markets, respectively. We compute the market-making index for the whole trading day, for the first and last 30 minutes of the trading day, and the rest of the trading day. For the futures market, we include only transactions for the contracts with expiry date 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 foreign institutions (FIIs), domestic mutual funds (MFs), and other long-term traders (OLTTs). We further split the STT category into the largest STTs (STT Top), who jointly generate 50% of STT trading volume, and small STTs (STT Not Top).

	Total		First 30 minutes		The rest of the trading day		Last 30 minutes	
	By trader	By category	By trader	By category	By trader	By category	By trader	By category
Panel A: Spot market								
LTT	76.6%	15.9%	88.0%	43.9%	79.0%	20.1%	87.9%	36.5%
FII	100.0%	67.2%	99.5%	88.1%	100.0%	70.5%	100.0%	80.2%
MF	96.7%	58.0%	100.0%	89.6%	98.2%	65.1%	98.8%	84.5%
OLTT	72.9%	27.6%	86.3%	48.3%	75.4%	30.3%	86.0%	50.3%
STT	50.7%	5.9%	74.6%	10.2%	56.3%	6.6%	79.5%	15.0%
STT Not Top	51.8%	6.7%	78.2%	13.4%	57.7%	7.4%	82.1%	15.7%
STT Top	26.6%	6.2%	44.5%	12.6%	29.0%	7.4%	50.7%	18.5%
Small	68.9%	11.0%	88.8%	19.9%	72.3%	12.4%	90.6%	20.4%
Panel B: Futures market								
LTT	72.6%	9.9%	89.4%	16.5%	74.5%	11.5%	89.8%	17.8%
FII	96.5%	81.5%	100.0%	90.6%	97.0%	82.4%	98.6%	85.3%
MF	90.3%	83.2%	100.0%	100.0%	98.2%	92.4%	100.0%	100.0%
OLTT	72.3%	12.8%	89.2%	19.5%	74.1%	14.1%	89.6%	17.8%
STT	58.6%	8.3%	74.0%	10.5%	61.7%	8.2%	78.2%	15.0%
STT Not Top	60.3%	8.7%	78.4%	11.1%	63.8%	8.6%	82.5%	17.8%
STT Top	26.8%	8.1%	46.5%	11.6%	29.2%	8.3%	50.5%	13.6%
Small	94.8%	31.5%	98.7%	47.6%	94.9%	36.5%	97.9%	44.5%

Table VII STTs' profits

This table shows the cost of liquidity provision by STTs as proxied by the daily profits STTs make as a whole, per trader, and per share traded with other trader categories. Profits are measured as the difference between selling volume and buying volume in rupees. Profits are winsorized at the 5% and 95% levels. We calculate profits under the assumption that STTs do not carry any inventory overnight. We report a t-statistic in parentheses of the t-test as to whether the average profits are significantly different from 0. ***, **, and * denote significance level at 1%, 5%, and 10%, respectively. We compute STTs' profits for the whole day, for the first and last 30 minutes of the trading day, and the rest of the trading day for the spot and futures markets, respectively. For the futures market, we include only transactions for the contracts with expiry date 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**		
	By category	By trader	By share	By category	By trader	By share
Total	7,570,360.67	11,089.05	4.90	21,998,340.25*	39,353.86**	7.70**
	(1.24)	(1.22)	(0.81)	(1.72)	(2.50)	(2.16)
First 30 minutes of the trading day	-8,034,066.43***	-50,156.70***	-60.62**	-25,082,494.70***	-131,134.85***	-65.13***
	(-2.77)	(-2.84)	(-2.39)	(-3.90)	(-4.53)	(-4.68)
The rest of the trading day	5,583,834.24	6,937.79	2.07	18,019,058.26	43,953.27 **	7.62
	(0.95)	(0.67)	(0.25)	(1.32)	(2.19)	(1.62)
Last 30 minutes of the trading day	11,020,822.94***	53,770.18 ***	81.14***	27,390,371.19 ***	111,551.78 ***	52.39***
	(3.54)	(4.11)	(4.64)	(4.32)	(3.64)	(3.70)

Table VIII Trading network during crashes

This table shows the average degree centrality measure (number of counterparties) of the bidirectional trading network (both buys and sells) as well as buy and sell networks for each trading category for spot (Panel A) and futures (Panel B) markets, respectively. We compute the degree centrality measure for the crash and recovery periods as defined -/+ 30 minutes from the crash's trough. For the futures market, we include only transactions for the contracts with expiry date within the same month as the transaction occurs. We classify traders into three categories: long-term traders (LTT), short-term traders (STT), and small traders (Small). We further split the LTT category into foreign institutions (FIIs), domestic mutual funds (MFs), and other long-term traders (OLTTs). We further split the STT category into the largest STTs (STT Top), who jointly generate 50% of STT trading volume, and small STTs (STT Not Top).

	Panel A: Spot market						**Panel B: Futures market**					
	Crash			Recovery			Crash			Recovery		
	Total	Buy	Sell	Total	Buy	Sell	Total	Buy	Sell	Total	Buy	Sell
LTT	40	9	30	36	19	16	3	2	2	4	3	2
FII	262	0	262	157	0	157	13	12	1	62	54	8
MF	56	53	3	83	73	9	-	-	-	11	11	-
OLTT	20	7	13	25	14	11	3	1	2	4	2	2
STT	25	12	13	23	10	12	5	3	2	6	3	3
STT Not Top	13	6	7	13	6	7	3	2	1	3	1	2
STT Top	262	116	146	198	97	101	25	14	12	28	13	15
Small	2	2	1	2	1	1	1	0	1	1	0	1

Table IX Market-making index during crashes

This table shows liquidity provision by trader categories as measured by market-making index ($\frac{|Passive\ buy\ volume - Passive\ sell\ volume|}{Passive\ buy\ volume + Passive\ sell\ volume}$). We report the market-making index for a trader category as a whole as well as on average for traders within each trader category for the spot (Panel A) and futures (Panel B) markets, respectively. We compute the market-making index for the crash and recovery periods as defined -/+ 30 minutes from the crash's trough. For the futures market, we include only transactions for the contracts with expiry date 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 foreign institutions (FIIs), domestic mutual funds (MFs), and other long-term traders (OLTTs). We further split the STT category into the largest STTs (STT Top), who jointly generate 50% of STT trading volume, and small STTs (STT Not Top).

	Panel A: Spot market				**Panel B: Futures market**			
	Crash		Recovery		Crash		Recovery	
	By trader	By category	By trader	By category	By trader	By category	By trader	By category
LTT	91.8%	16.0%	93.4%	43.9%	90.6%	10.2%	86.3%	17.5%
FII	100.0%	100.0%	100.0%	100.0%	100.0%	97.5%	100.0%	64.1%
MF	100.0%	97.0%	100.0%	85.3%	-	-	100.0%	100.0%
OLTT	89.9%	36.6%	91.5%	50.9%	90.3%	4.8%	85.9%	11.9%
STT	72.6%	17.5%	71.3%	6.1%	70.0%	19.3%	74.3%	19.0%
STT Not Top	76.0%	25.3%	75.0%	5.9%	75.6%	17.8%	80.6%	17.5%
STT Top	40.7%	10.2%	34.4%	10.9%	46.4%	21.4%	49.8%	21.1%
Small	89.2%	41.2%	85.1%	16.2%	96.7%	49.4%	97.5%	27.0%

Table X Trading activity regression during 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 through 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 crash's trough. We estimate regression without a constant. We use day and time fixed effects. We cluster standard errors by day. ***, **, and * denote 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 R^2					0.358					0.449	

Table XI Inventory sensitivity to price movements during crashes

This table shows the results of the inventory-sensitivity regression estimation based on one-minute intervals from 16-May-2006 through 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 crash's trough. 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. ***, **, and * denote 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 R^2	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 R^2	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 XII Cash flow regression for STTs during crashes

This table shows the results of the cash flow regression estimation based on one-minute intervals from 16-May-2006 through 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 crash's trough (see equation (6)). We use day and time fixed effects. We cluster standard errors by day. ***, **, and * denote 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**		
	STT-All	STT-Both	STT-Spot	STT-All	STT-Both	STT-Futures
Down	-0.241	-0.192	0.013	-2.289	-0.631	-1.690*
	(-0.71)	(-0.63)	(0.23)	(-1.77)	(-1.28)	(-2.26)
Up	0.300	-0.002	-0.024	2.446	1.472	0.886
	(1.35)	(-0.01)	(-0.31)	(1.03)	(1.19)	(1.14)
Constant	-0.093	-0.052	0.053	0.545	-0.106	0.546*
	(-0.59)	(-0.32)	(0.89)	(1.07)	(-0.56)	(2.02)
Day FE		Yes			Yes	
Time FE		Yes			Yes	
Cluster SE		By Day			By Day	
Observations	1,871	1,709	1,839	1,871	1,709	1,839
Adjusted R^2	0.002	-0.003	0.003	0.012	0.007	0.006

Table XIII 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 crash's trough. 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 XIV 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 crash's trough. 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 XV Quality of LTTs' trade execution

This table shows the regression for the terms of execution LTTs face 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 May 19 and/or May 22, 2006. We use day fixed effects. We cluster standard errors by day and trader. ***, **, and * denote 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 R^2	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 XVI 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	0.039	0.844	Ret	MOIB FII	8.913	0.003
Ret	MOIB MF	2.451	0.117	Ret	MOIB MF	0.257	0.612
MOIB FII	Ret	3.361	0.067	MOIB FII	Ret	0.138	0.710
MOIB FII	MOIB MF	0.300	0.584	MOIB FII	MOIB MF	0.891	0.345
MOIB MF	Ret	0.564	0.453	MOIB MF	Ret	0.018	0.892
MOIB MF	MOIB FII	0.012	0.914	MOIB MF	MOIB FII	0.007	0.933
Panel C: Spot and Futures market							
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.

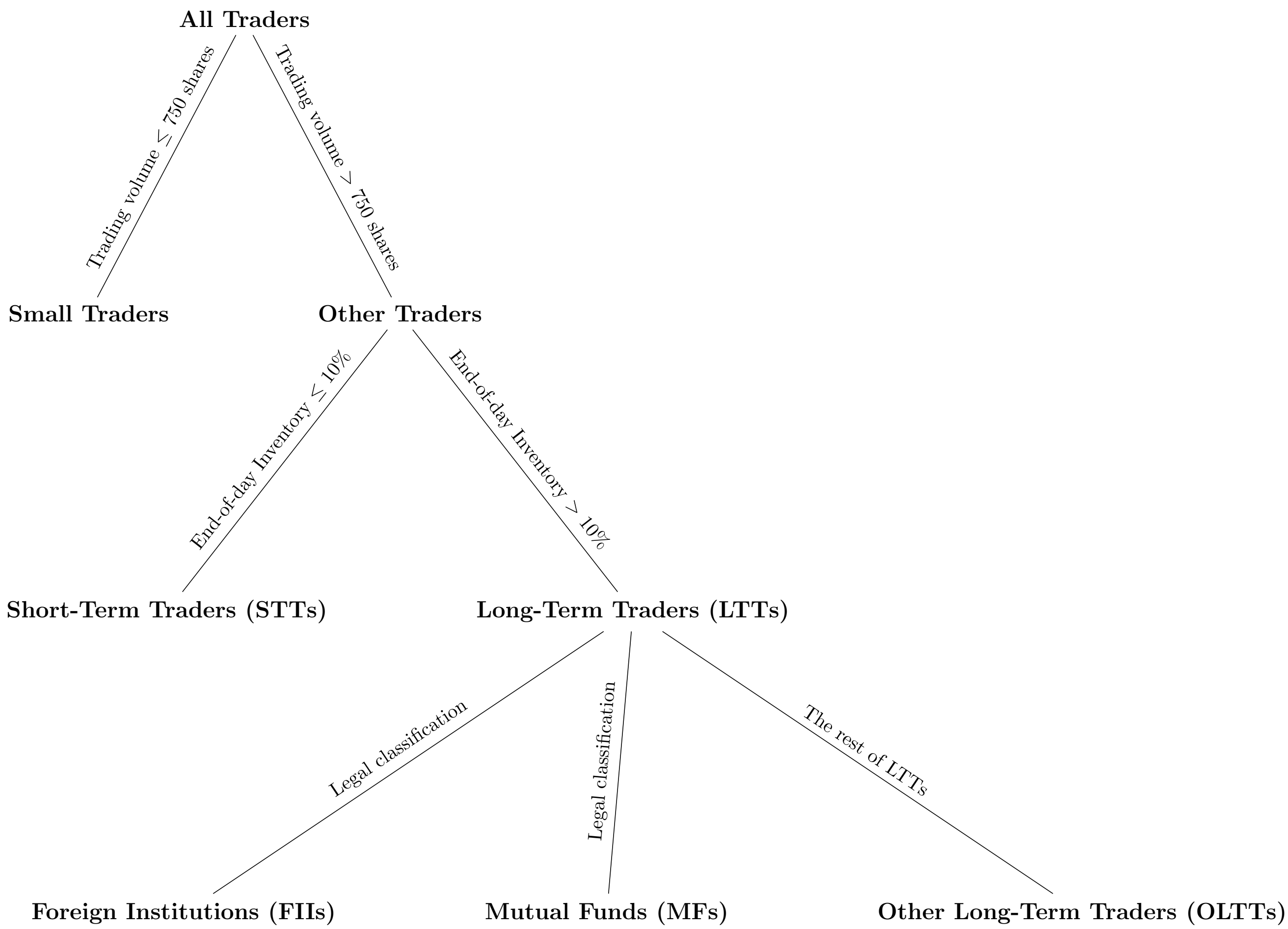


Figure 2. Trading network

This figure shows the trading network for the spot and futures markets for April-June, 2006, where each vertex corresponds to the trader type; the size of the vertex represents the proportion of total trading volume; and the width of the edges represents the proportion of total trading volume between two categories.

Panel A: Spot market

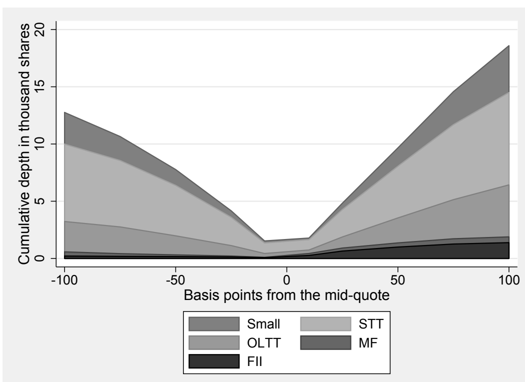
Panel B: Futures market

Figure 3. Limit order book

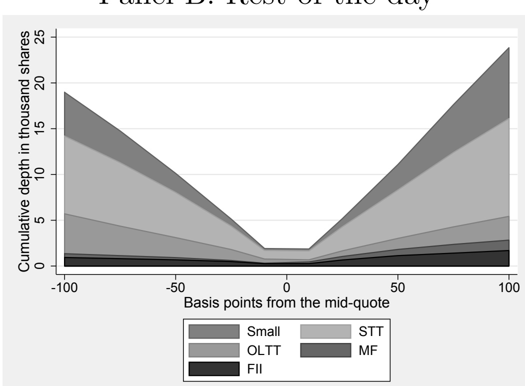
This figure shows the average of one-minute median depth in the proximity (in basis points) to the mid-quote, where negative values of the price deviation from the mid-quote correspond to the bid side of the limit order book, while positive values of the price deviation from the mid-quote correspond to the ask side of the limit order book. We plot cumulative depth (in 1,000 shares) within 10, 25, 50, and 100 basis points from the mid-quote for the first 30 minutes of the trading day, the last 30 minutes of the trading day, and the rest of the trading day for the spot (Panels A-C) and futures (Panels D-F) markets, respectively. We show the cumulative depth available in the close proximity of the mid-quote coming from all traders and coming from STTs only.

Spot market

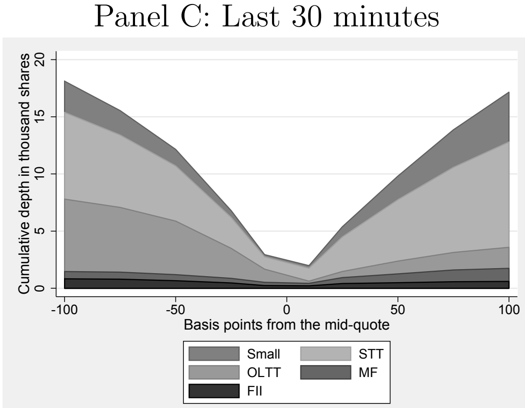
Panel A: First 30 minutes



Panel B: Rest of the day

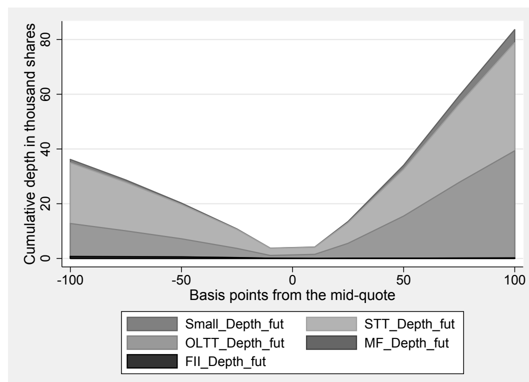


Panel C: Last 30 minutes

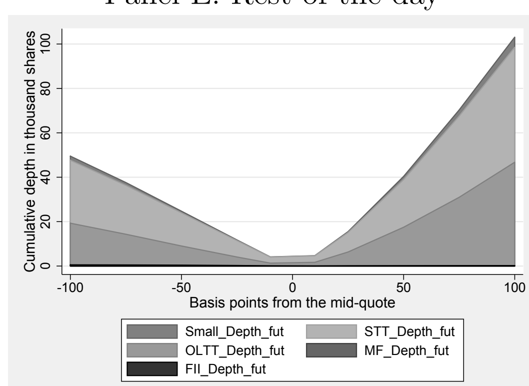


Futures market

Panel D: First 10 minutes



Panel E: Rest of the day



Panel F: Last 10 minutes

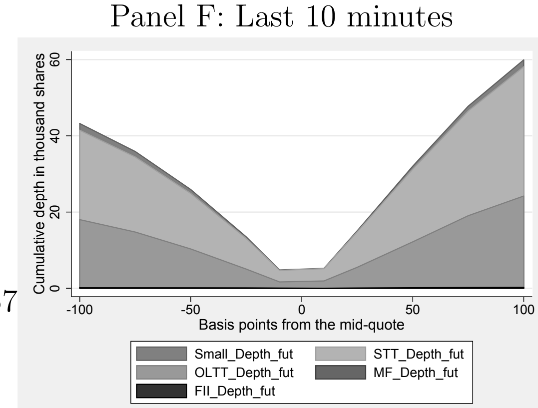
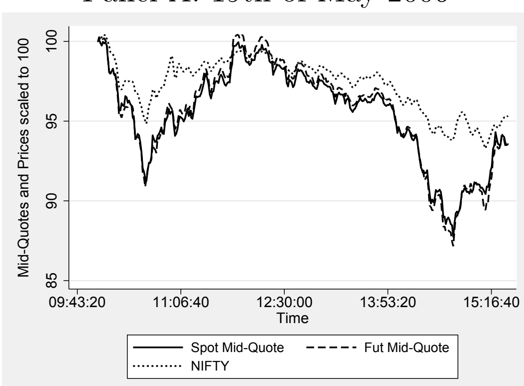


Figure 4. Crashes

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 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

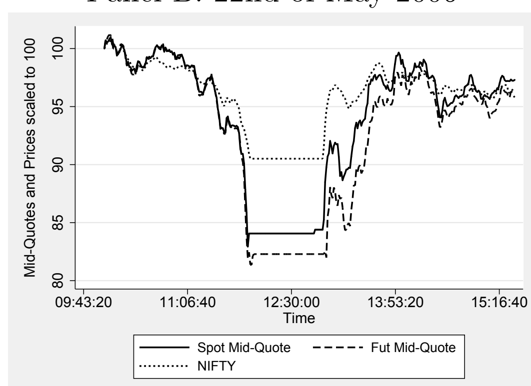
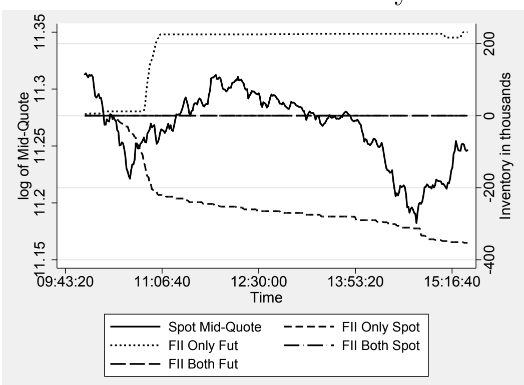


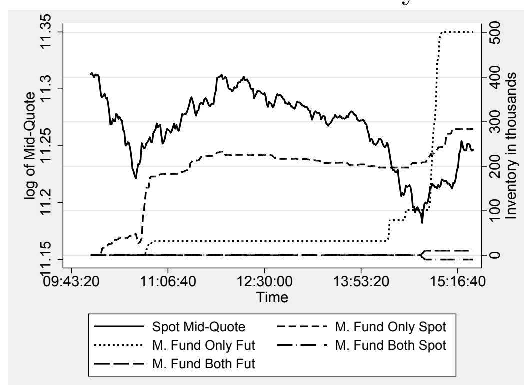
Figure 5. Inventory dynamics for FIIs and MFs during the crashes

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 crash days: May 19 and May 22, 2006.

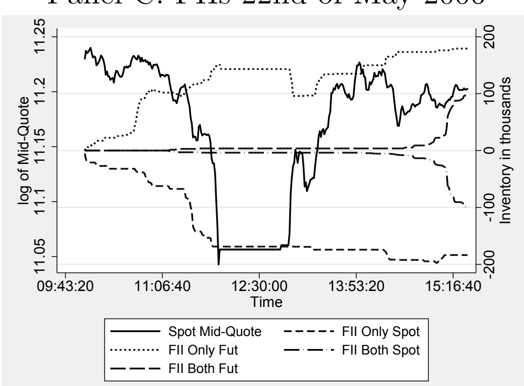
Panel A: FIIs 19th of May 2006



Panel B: MFs 19th of May 2006



Panel C: FIIs 22nd of May 2006



Panel D: MFs 22nd of May 2006

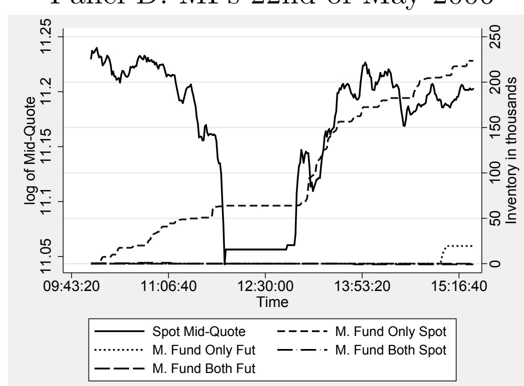


Figure 6. Arbitrage proxies

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 crash days: May 19 and May 22, 2006.

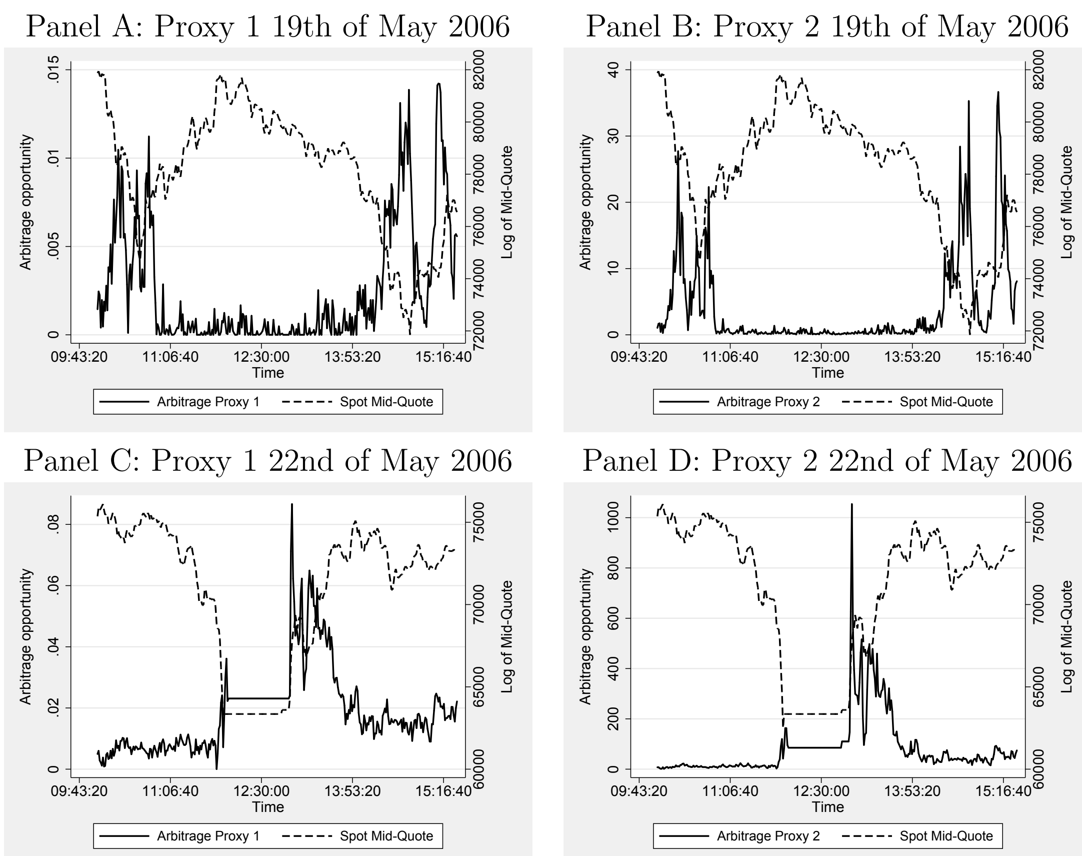
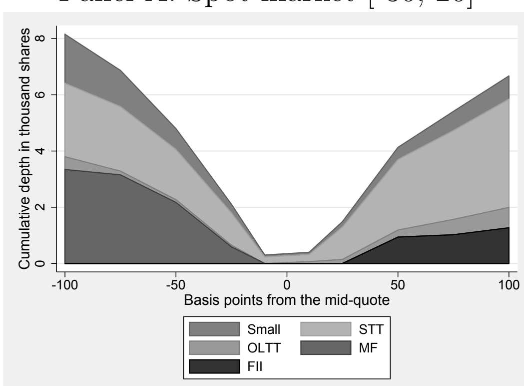


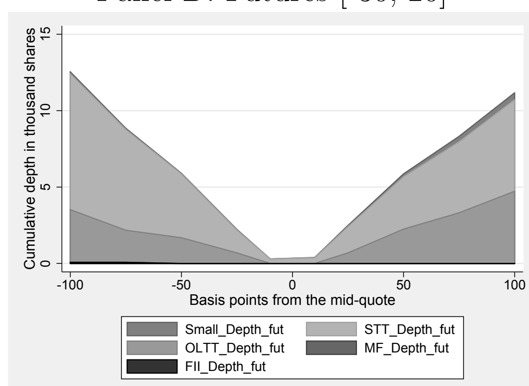
Figure 7. Limit order book during crash on May 19 and May 22, 2006

This figure shows the average of one-minute median depth in the proximity (in basis points) to the mid-quote during the crashes on May 19 and May 22, 2006, where negative values of the price deviation from the mid-quote correspond to the bid side of the limit order book, while positive values of the price deviation from the mid-quote correspond to the ask side of the limit order book. We plot cumulative depth (in 1,000 shares) within 10, 25, 50, and 100 basis points from the mid-quote for -30 to -20 minutes before the crash's trough, from -20 to -10 minutes before the crash's trough, and from -10 minutes before the crash to the trough for the spot (Panels A-C) and futures (Panels D-F) markets, respectively. 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).

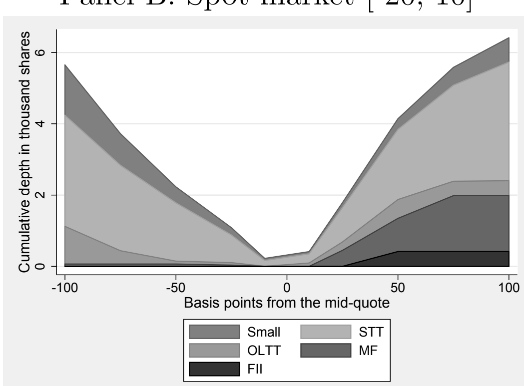
Panel A: Spot market [-30,-20]



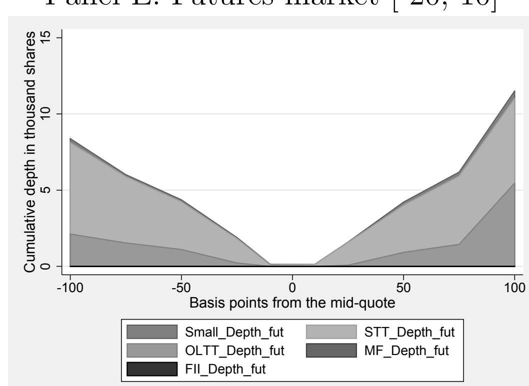
Panel D: Futures [-30,-20]



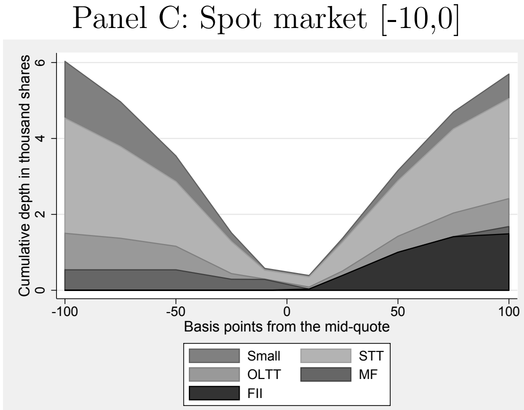
Panel B: Spot market [-20,-10]



Panel E: Futures market [-20,-10]



Panel C: Spot market [-10,0]



Panel F: Futures market [-10,0]

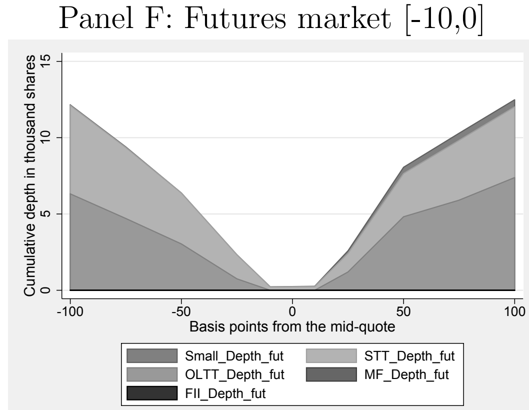
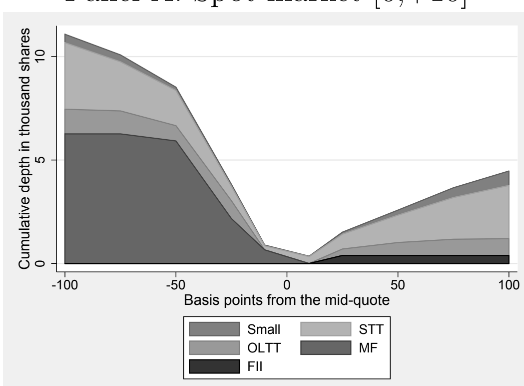


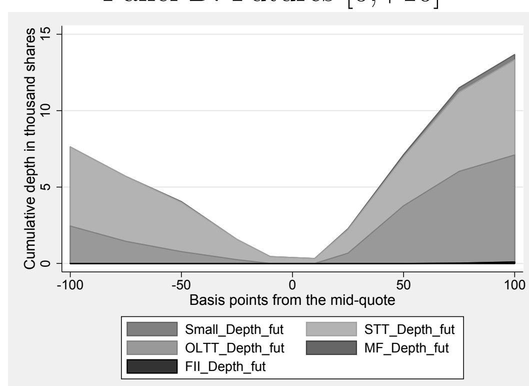
Figure 8. Limit order book during recovery on May 19 and May 22, 2006

This figure shows the average of one-minute median depth in the proximity (in basis points) to the mid-quote during recovery on May 19 and May 22, 2006, where negative values of the price deviation from the mid-quote correspond to the bid side of the limit order book, while positive values of the price deviation from the mid-quote correspond to the ask side of the limit order book. We plot cumulative depth (in 1,000 shares) within 10, 25, 50, and 100 basis points from the mid-quote for the trough to +10 minutes after the crash's trough, from +10 to +20 minutes after the crash's trough, and from +20 to +30 minutes after the crash's trough for the spot (Panels A-C) and futures (Panels D-F) markets, respectively. 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).

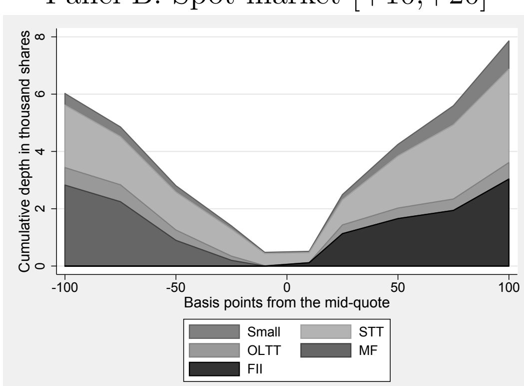
Panel A: Spot market [0,+10]



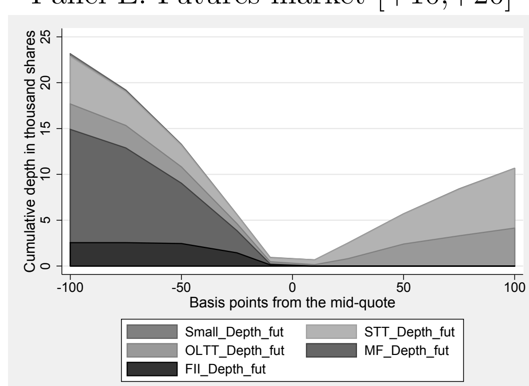
Panel D: Futures [0,+10]



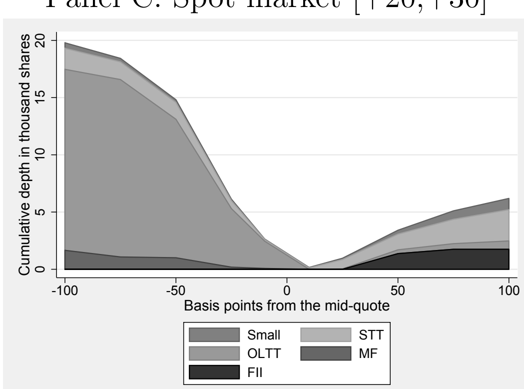
Panel B: Spot market [+10,+20]



Panel E: Futures market [+10,+20]



Panel C: Spot market [+20,+30]



Panel F: Futures market [+20,+30]

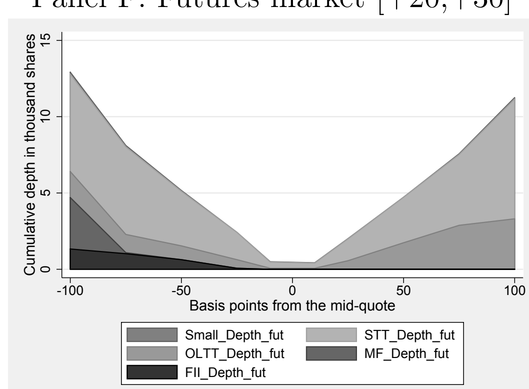
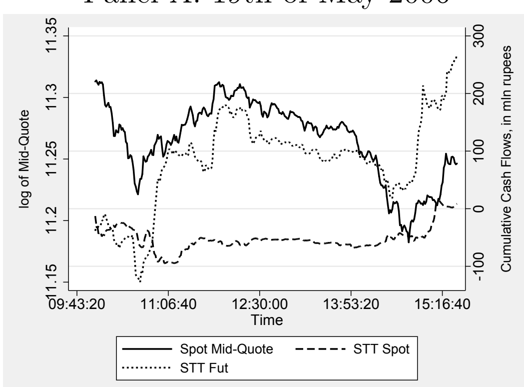


Figure 9. STTs' cumulative cash flows during the crashes

This figure shows STTs' cumulative cash flows of STTs at a one-minute frequency for the spot and futures markets during the two 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) transactions.

Panel A: 19th of May 2006



Panel B: 22nd of May 2006

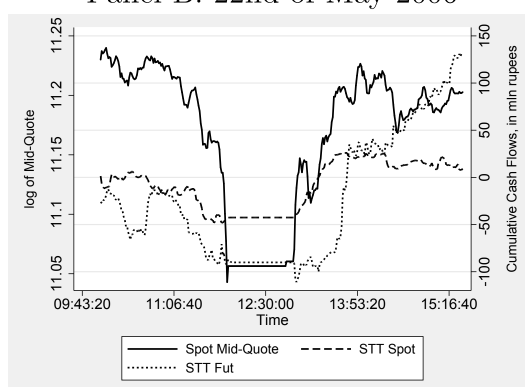


Figure 10. STTs' activity during the two crash days

This figure shows shows STTs' activity 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 crash's trough. 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% of the maximum inventories on non-crash days).

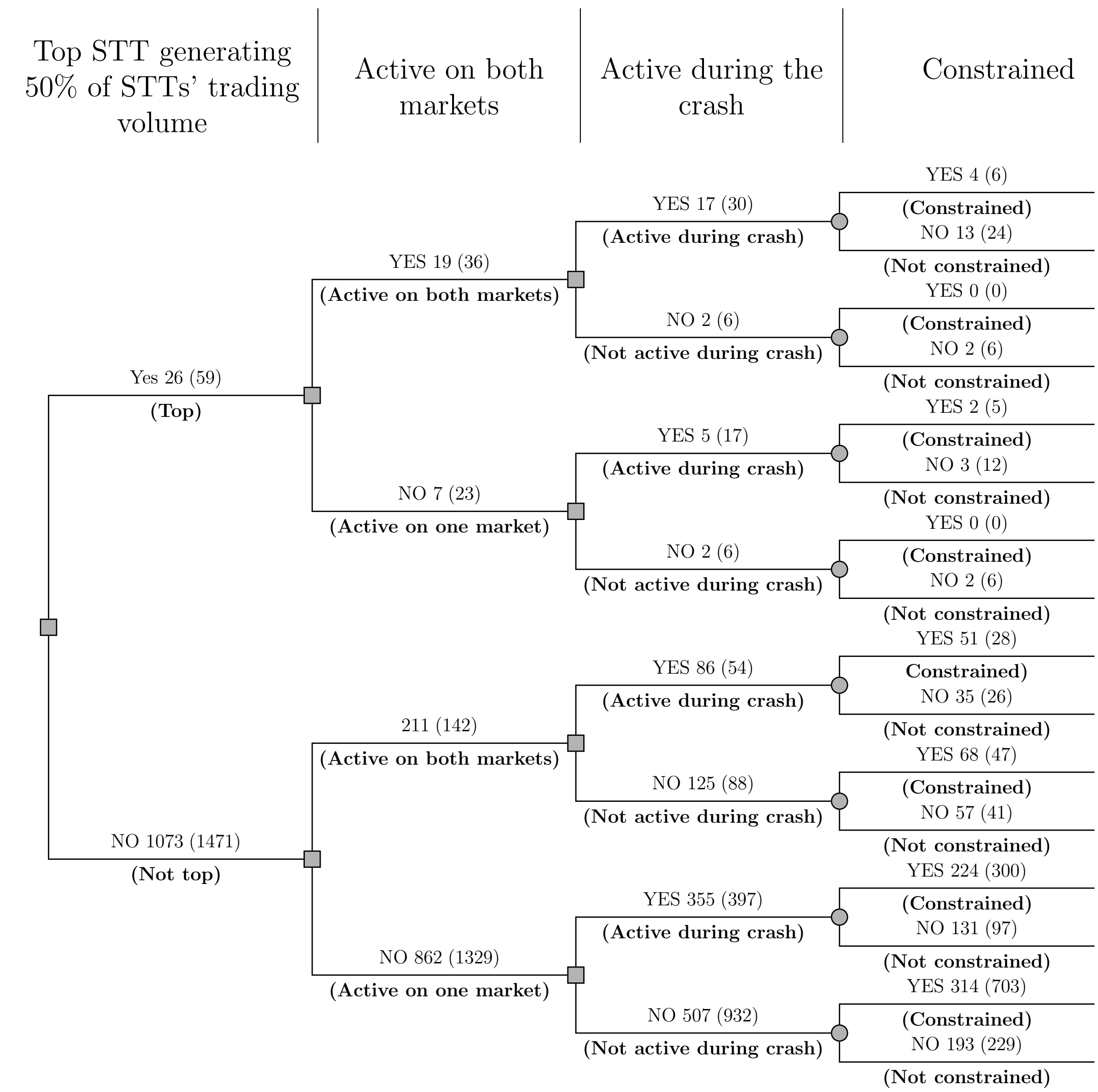
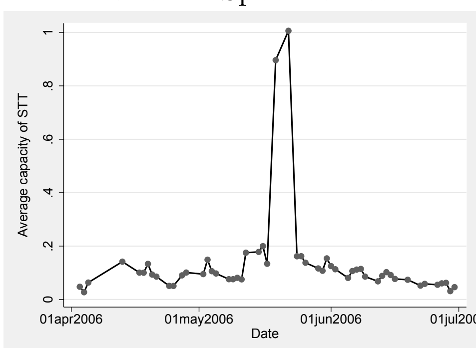


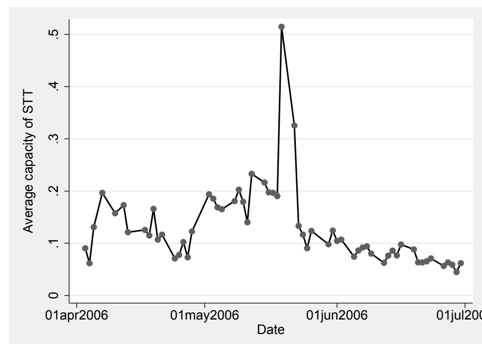
Figure 11. STTs' inventory capacity

This figure shows STTs' average 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 the 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 the two crash days (May 19 and May 22, 2006) for the spot and futures markets, respectively, for May 19 (22), 2006.

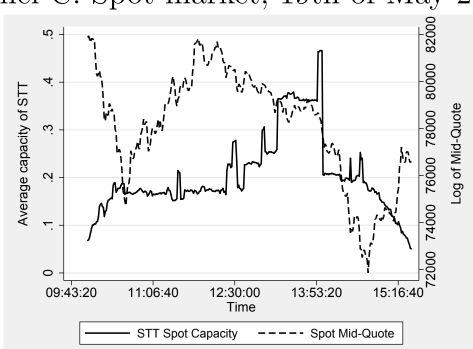
Panel A: Spot market



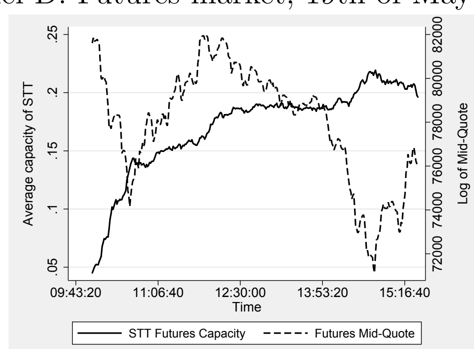
Panel B: Futures market



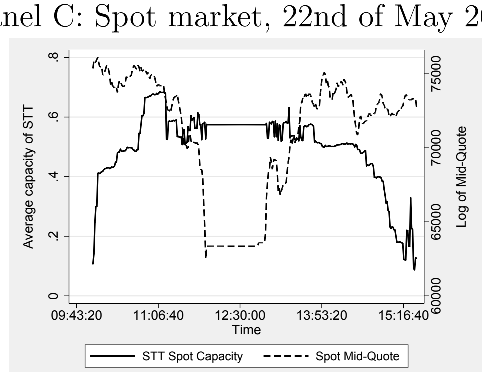
Panel C: Spot market, 19th of May 2006



Panel D: Futures market, 19th of May 2006



Panel C: Spot market, 22nd of May 2006



Panel D: Futures market, 22nd of May 2006

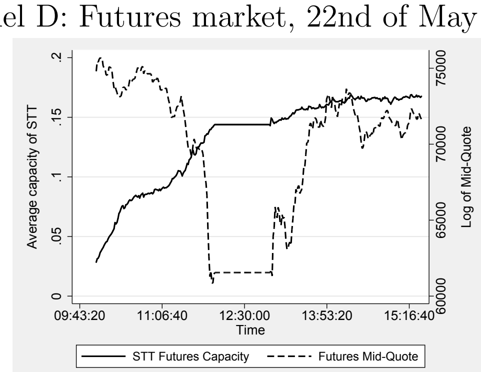
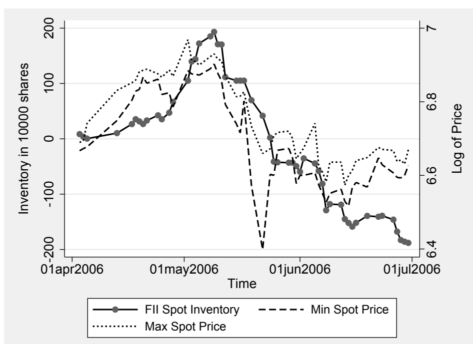


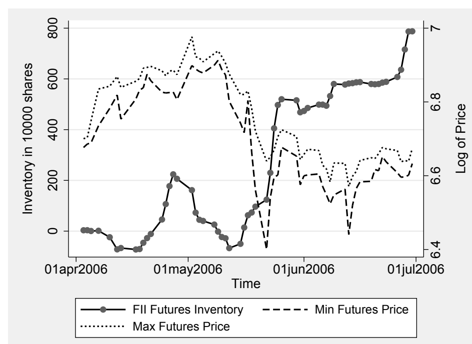
Figure 12. FIIs' cumulative inventories

This figure shows FIIs' cumulative end-of-day inventory position 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 in the starting position as of the beginning of April 2006.

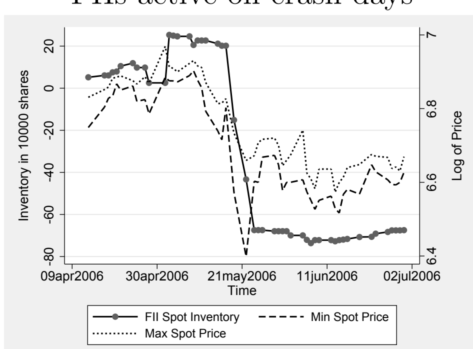
Panel A: Spot market:
all FIIs



Panel B: Futures market:
all FIIs



Panel C: Spot market:
FIIs active on crash days



Panel D: Futures market:
FIIs active on crash days

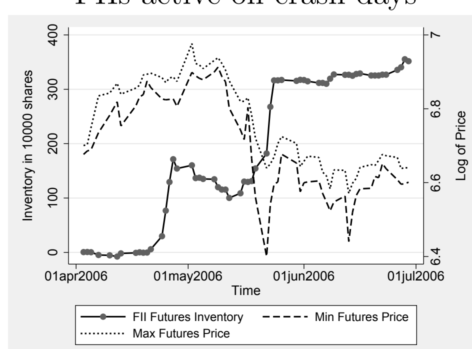
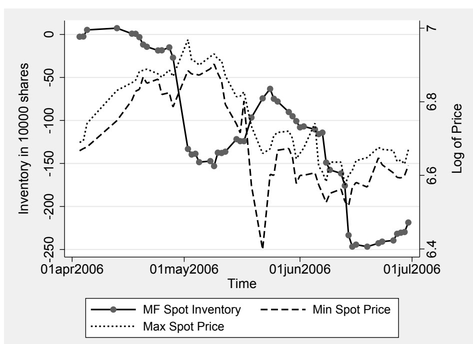


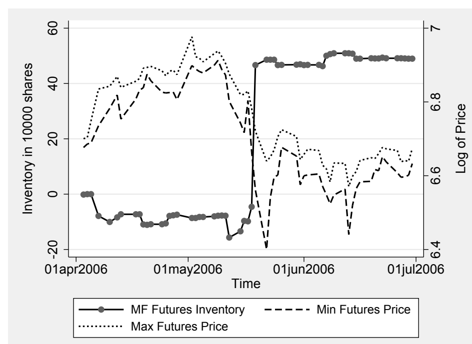
Figure 13. MFs' cumulative inventories

This figure shows MFs' cumulative end-of-day inventory position 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 in the starting position as of the beginning of April 2006.

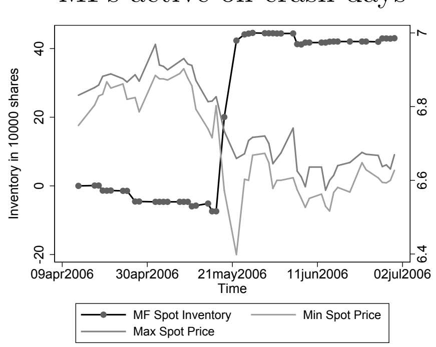
Panel A: Spot market:
all MFs



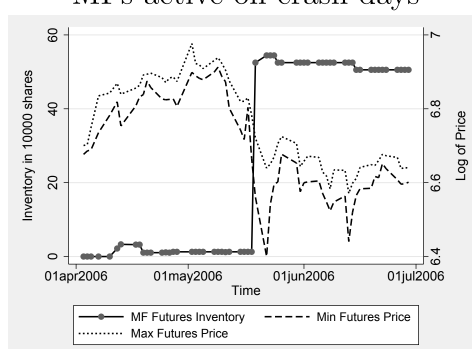
Panel B: Futures market:
all MFs



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 of India Ltd. (NSE) 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. to 16:00 p.m., only for the spot market. Figure A1 show the trading day timeline in more detail.

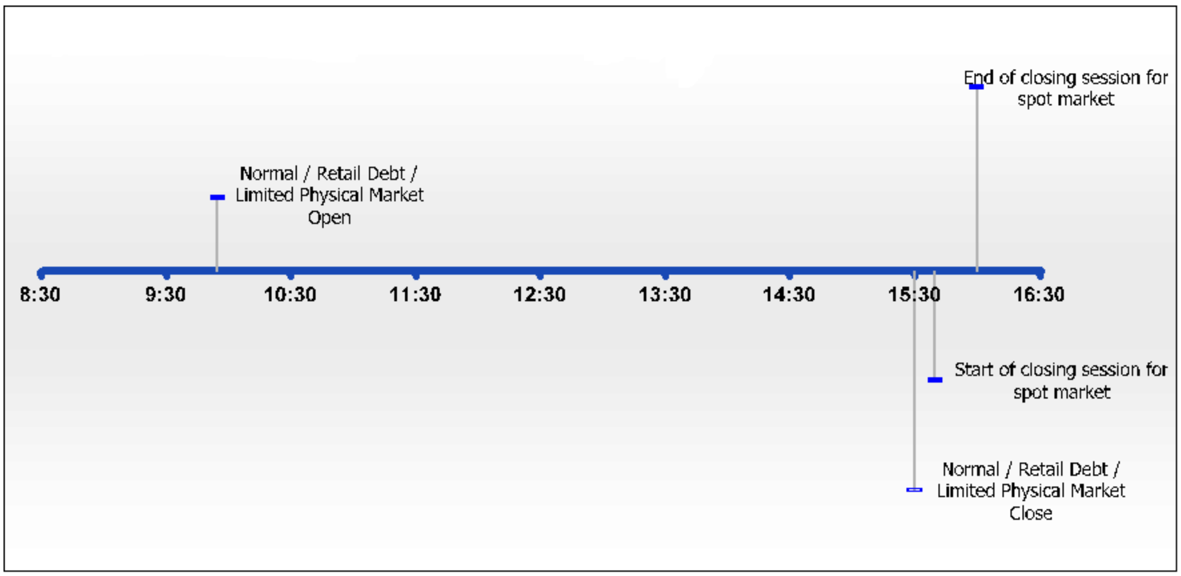
Appendix B Persistence of STTs

On a given day, we classify traders into small traders (Small), long-term traders (LTTs), and short-term traders (STTs). To determine a trader's final category, 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 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, and 5%, 50%, and 95% persistence ratios) 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%

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