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ORIGINAL RESEARCH

Dynamic limit order placement activities and their effects on stock market quality

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Abstract
This study examines the interaction between dynamic limit order placement activities and market quality around the two system upgrades by the Australian Securities Exchange (ASX) which aims at reducing the latency of trades. We show that after the 2006 system upgrade from Stock Exchange Automated Trading System to Integrated Trading System, liquidity falls and short-term volatility heightens. Lower latency provides capacity for traders to position themselves to take liquidity when it is cheap. After the second upgrade in 2010 (launch of ASX Trade), the harmful effect reverses. Our evidence shows that in large-capitalisation stocks, algorithmic trading/high-frequency trading provides liquidity and stabilises the price when short-term volatility is high. Since we find that the market quality could be unfavourably affected after a system upgrade (i.e., the 2006 system upgrade), regulators need to be prepared for near-time reactions and rapid investigations in the event of market stress.

Keywords Dynamic limit order placement strategies · Stock market quality · Latency

JEL Classification C35 · G15

1 Introduction

Dynamic order placement strategies play a major role in financial markets, especially in the past decade (Le et al., 2020, 2021). They have facilitated trading activities of large institutional traders as well as individual traders, especially through algorithmic trading/high-frequency trading (AT/HFT) in recent periods. It has been observed that order placement strategies, especially with trading algorithms, enable traders to be more active in managing their orders

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to buy or sell stocks. However, the efficiency of these activities and the extent to which they affect the stock market quality are still debatable issues. The recent disastrous incidents involving trading algorithms that happened to the largest stock markets in the world, including the stock market flash crash in May 2010 and Knight Capital's trading glitch in August 2012, have raised even more questions on the effectiveness of these types of dynamic order placement activities.

The existing literature has largely focused on dynamic order placement strategies with the selection of market orders or limit orders (see, for example, Harris & Hasbrouck, 1996; Parlour, 1998; Ahn et al., 2001; Cao et al., 2008; Cont & Kukanov, 2017); or order submission strategies where traders choose among market orders, limit orders, reserve (partially undisclosed) orders, and hidden (totally invisible) orders (see Bacidore et al., 2003; Buti & Rindi, 2013; Yamamoto, 2020). Other researchers argue that transaction costs act as a motive for order placement strategies (Cohen et al., 1981; Kissell et al., 2004). Fung and Hsieh (1997) also investigate the empirical characteristics of dynamic trading activities conducted by hedge funds. However, most of these existing studies have seemingly ignored the fact that limit orders can be revised or cancelled. Fong and Liu (2010), among a limited number of research papers, take into account the importance of limit order revision and cancellation. They find that the time of the trading day, order aggressiveness, order size, market liquidity, market volatility, and depth of the limit order book are factors that contribute to the level of revision and cancellation activities. Another study, conducted by Cao et al. (2008), also examines order placement activities in the Australian Stock Exchange and shows that the top of the limit order book impacts limit order submission, revision, and cancellation; the rest of the book mostly affects order revision and order cancellation. These studies, however, do not investigate to a full extent the influence that these dynamic limit order placement activities have on the quality of the stock markets.

Several studies on the nexus between low latency and market quality provide mixed evidence on whether reduced latency improves or worsens market liquidity. Jain et al. (2016) analyse latency reductions from 6 s to 2 ms following the introduction of Arrowhead—the high-speed trading platform by the Tokyo Stock Exchange—in January 2010. They find that HFT increases systemic risk, and they also show that HFT associates with an improvement in market quality, through increases in trading speed, volume, and the number of trades, as well as limit order book liquidity. Brogaard et al. (2015) employ probit regressions to show that enhanced trading speed due to an optional co-location upgrade at NASDAQ OMX Stockholm in September 2012 leads to the improvement in overall market liquidity. Specifically, their results reveal that the trading firms that opt for the upgrade service tend to reduce their adverse selection costs, improve their inventory management ability, and hence provide more liquidity. Riordan and Storkenmaier (2012) examine the impact of system upgrade in 2007 at Deutsche Boerse that reduces system latency from 50 to 10 ms. They find that the fall of both quoted and effective spreads (among small and medium-sized stocks) is associated with a reduction in adverse selection costs. On the contrary, Hendershott and Moulton (2011) examine how the market quality is affected by decreases in latency of market order execution from 10 to 1 s following the Hybrid Market's introduction in the New York Stock Exchange (NYSE) in 2006, they show that spread cost increase by about 10%, which can be attributed to higher adverse selection. Easley et al. (2014) analyse the impact of a major upgrade to the NYSE's trading environment on stock prices. They find that the upgrade that associates with reduced latency is associated with a positive and significant effect on liquidity, which in turn leads to abnormal returns.

A closely related study by Murray et al. (2016) uses a similar event study approach to examine the effect of both ASX system upgrades on market liquidity. They find that market liquidity falls after the 2006 system upgrade to ITS. They show that there is no discernible impact on market liquidity after the 2010 system upgrade and they argue that this may be due to the fact that investors have already had access to the Bondi co-location facility that enables them to trade faster than the ASX Trade platform. However, their methodology (OLS) fails to account for endogeneity, which makes their conclusion somewhat debatable.

To gain a better understanding of the effects of dynamic order placement activities, it is important to understand the linkages between the multiple events within the life of each order and to connect them in a meaningful way. The majority of the existing literature solely concerns with a single event that occurred subsequently to an order submission. Lo et al. (2002), for example, consider only order execution in studying the time-to-an-order-event and do not examine order revision and cancellation in their research. Other studies arbitrarily link order submission, execution, and cancellation based on the order size and direction (see, for example, Hasbrouck & Saar, 2013; Van Ness et al., 2015). This research aims to contribute to the current literature by examining order revision and cancellation of limit orders as parts of a dynamic strategy. It utilises a reliable approach to construct a full limit order life with order events that are non-arbitrarily linked to each other based on unique order identifiers that attached to each order.

Another major contribution of this study is analyzing the effects of dynamic limit order placement activities in a unique context. This study contributes to the current literature by providing an investigation into the revision and cancellation as well as execution activities of buy/sell limit orders, dynamically managed by financial traders. We employ an event study approach to examine two Australian Securities Exchange (ASX) system upgrades on October 6th, 2006, and November 29th, 2010. For each of them, we consider an event window of one day, and analyse one month prior to and one month after the event window. To address endogeneity, which may occur when any change of liquidity may induce traders to act which in turn affects liquidity, we follow Hasbrouck and Saar's (2013) Two-Stage Least Squares which enables us to examine the interrelation between dynamic limit order placement activities and market quality.

We find evidence that dynamic limit order placement activities have a negative impact on the stock market quality in the earlier period before the 2006 system upgrade. Specifically, they reduce the level of liquidity. This unfavourable impact is also observed in the periods following the first structural changes of the ASX. In particular, an increase in limit order placement activities, including revising and cancelling the submitted limit orders, is harmful to the quality of the stock market by heightening short-term volatility, widening the spreads while having negligible impacts on the depth of the limit order book. However, a mixed picture is revealed for the second system upgrade. AT/HFT appears to provide liquidity in large-capitalisation (large-cap) stocks, as the technological upgrade increases the capacity for AT/HFT to engage aggressively in processing their algorithms in response to rapid change market environment. The opposite appears to be true for small-capitalisation (small-cap) stocks, as AT/HFT seems to demand liquidity. For both system upgrades, regardless of small or large-cap stocks, dynamic limit order placement activities do not appear to have a significant impact on the depth of the limit order book. Nevertheless, it has been viewed that, traders dynamically manage their order placement activities in an attempt to respond to certain stock market conditions. In particular, traders are more motivated to increase their order placement activities in terms of revising or cancelling their submitted limit orders when the market becomes less volatile or more liquid. Traders are, required to be more active in monitoring their submitted limit orders, especially when the market conditions alter adversely. The findings of this study are not only valuable for academics but also useful for market participants in enhancing their knowledge and understanding of dynamic limit order placement activities.

The study's conclusions are also helpful for market regulators by contributing to effective regulation settings in order to ensure a more stable and well-functioning stock exchange.

The rest of this study proceeds as follows. Section 2 describes the order flow data and the statistics that show order activities in the ASX during the investigation periods. Section 3 explains the construction of measures for dynamic limit order activities and explanatory variables, the methodological approach as well as the specification of the empirical model employed in this study. Section 4 presents the empirical results of the analysis and the robustness check, discusses the significance of the findings in the context of the current literature. Finally, Sect. 5 concludes the study with policy implications.

2 Order flow data

The Australian Securities Exchange (ASX) is a securities market that relies solely on liquidity provision by investors and trading activities on the exchange are dominated by limit orders. In fact, the majority of the equity turnover on the ASX is facilitated by limit orders. This study investigates the dynamic limit order placement activities of the 40 index stocks listed on the ASX over the two sample periods, the year 2006 and the year 2010. Each sample contains 20 large and 20 small stocks, ranked by market capitalisation. Large-cap stocks are the top 20 common stocks that are traded on the ASX200 index.[1] Small-cap stocks are the 20 common stocks ranked 111th to 130th on the ASX200 index.

The ASX's fully computerised Stock Exchange Automated Trading System (SEATS) was introduced in October 1987. Since then, there have been two major ASX system upgrades, which seem to correlate with the higher levels of AT/HFT in ASX over years.[2] To study the impact of these two upgrades on dynamic limit order placement activities, we employ an event study approach. On October 6th, 2006, the exchange introduced the Integrated Trading System (ITS) to replace SEATS. ITS is a fully electronic trading system utilised with the purpose to provide quicker and more efficient transactions. It reduces the system latency from 70 to 30 ms. On November 29th, 2010, ASX Trade was put in place to replace ITS. ASX Trade is an ultra-low latency trading platform, which reduces the system latency down to 300 µs It is powered by NASDAQ OMX's Genium INET platform, providing one of the fastest integrated equities and derivative platforms in the world. As a result, the date of November 29th, 2010, is chosen as the event date for the purpose of this research. For both upgrades, the event window comprises only the event date.[3] We analyse compare the interaction between market quality and dynamic limit order placement activities over the one-month period prior to the event date and the one-month period after the event. Specifically, our pre-event (post-event) 2006 sample covers the period from September 5th, 2006 to October 5th, 2006 (October 7th, 2006 to November 7th, 2006). Similarly, our pre-event (post-event) 2010 sample covers the period from October 28th, 2010 to November 28th, 2010 (November 30th, 2010 to December 30th, 2010). We choose a relatively short window (one month) to reduce possible contamination

[1] ASX200 is Australia's primary stock market index and contains the top 200 ASX listed companies by float-adjusted market capitalisation. ASX200 index came into operation in 2000 and acts as the benchmark for Australian equity performance.

[2] According to Frino et al. (2011), AT/HFT participation in Australia, in terms of daily dollar value proportion of HFT trades, ranged between 30 and 80% for the period of October 2006 and October 2009. According to ASIC reports, as of November 2010, ASX participants estimate their levels of AT/HFT at 30–40% of total volumes traded. From May to July 2012, the percentages of HFT in the total number of orders for new, revised, and cancelled orders are estimated at 61%, 60%, and 59%, respectively.

[3] For robustness, we extend the event window to 2 months and our conclusion remains largely unchanged.

from both the general rising trend of HFTs and other events that might interfere with the dynamic relation. The data records each order and trade, including the date, time, stock code, price, transacted volume, and order types. The types of orders, including revision and cancellation, are also recorded separately for each order event. The dataset is provided by the Securities Industry Research Centre of Asia–Pacific (SIRCA).

Table 1 reports an example of the frequency and the order events of market and limit orders in the sample under study. The statistics are reported separately for large-cap stocks (Panel A), small-cap stocks (Panel B) for one month prior to and one month after the system upgrade on October 6th, 2006, as well as for large-cap stocks (Panel C), small-cap stocks (Panel D) for one month prior to and one month after the system upgrade on November 29th, 2010. The statistics show the proportion of the market and limit orders in the total number of order submissions, the ratios of order revision and order cancellation to limit order submissions; and the ratios of order revision and order cancellation to the total number of order submissions. The numbers are presented individually for buy and sell orders.

Table 1 The trading activities of limit orders and market orders in the Australian stock exchange

Order events	Number of order events				Proportion of submission (%)			
	Buy		Sell		Buy		Sell	
	Pre	Post	Pre	Post	Pre	Post	Pre	Post
Panel A: Large-cap stocks sample—one month prior to and one month after the system upgrade on the October 6th, 2006								
Market order	63440	60920	66475	62267	8.5	8.6	11.8	10.6
Limit order	683931	646098	496080	523709	91.5	91.4	88.2	89.4
Revision	224343	212259	191572	196100				
Cancellation	301	1027	196	1524				
Panel B: Small-cap stocks sample—one month prior to and one month after the system upgrade on the October 6th, 2006								
Market order	8536	8639	9287	9147	6.1	5.9	7.3	7.7
Limit order	132390	138036	118056	109427	93.9	94.1	92.7	92.3
Revision	38992	35555	32575	32157				
Cancellation	133	243	26	205				
Panel C: Large-cap stocks sample—one month prior to and one month after the system upgrade on November 29th, 2010								
Market order	235763	173727	209372	165879	6.2	5.6	6.3	6.5
Limit order	3548749	2913522	3110268	2402991	93.8	94.4	93.7	93.5
Revision	3005894	2760499	3096876	2604108				
Cancellation	10221	8667	13946	8783				
Panel D: Small-cap stocks sample—one month prior to and one month after the system upgrade on November 29th, 2010								
Market order	39308	35401	38445	38378	5.0	4.4	5.4	5.6
Limit order	754398	775549	676686	646326	95.0	95.6	94.6	94.4
Revision	673877	640818	702206	590879				
Cancellation	935	1140	1874	1157				

Table 1 (continued)

Order events	Ratio of revision and cancellation to limit order submission (%)				Ratio of revision and cancellation to total order submission (%)			
	Buy		Sell		Buy		Sell	
	Pre	Post	Pre	Post	Pre	Post	Pre	Post
Panel A: Large-cap stocks sample—one month prior to and one month after the system upgrade on the October 6th, 2006								
Market order								
Limit order								
Revision	32.8	32.9	38.6	37.4	30.0	30.0	34.1	33.5
Cancellation	0.04	0.16	0.04	0.29	0.04	0.15	0.03	0.26
Panel B: Small-cap stocks sample—one month prior to and one month after the system upgrade on the October 6th, 2006								
Market order								
Limit order								
Revision	29.5	25.8	27.6	29.4	27.7	24.2	25.6	27.1
Cancellation	0.10	0.18	0.02	0.19	0.09	0.17	0.02	0.17
Panel C: Large-cap stocks sample—one month prior to and one month after the system upgrade on November 29th, 2010								
Market order								
Limit order								
Revision	84.7	94.7	99.6	108.4	79.4	89.4	93.3	101.4
Cancellation	0.29	0.30	0.45	0.37	0.27	0.28	0.42	0.34
Panel D: Small-cap stocks sample—one month prior to and one month after the system upgrade on November 29th, 2010								
Market order								
Limit order								
Revision	89.3	82.6	103.8	91.4	84.9	79.0	98.2	86.3
Cancellation	0.12	0.15	0.28	0.18	0.12	0.14	0.26	0.17

This table presents the frequency of market and limit orders one month prior to and after the system upgrades in 2006 and 2010. We also report the proportions of market and limit orders, ratios of limit order revision and cancellation

Table 1 shows to the importance of considering both limit order revision and cancellation as part of dynamic limit order placement activities. During the period of one month prior to and one month after the ASX system upgrade on October 6th, 2006, for the sample of small-cap stocks, a range of 25.8–29.5% of limit orders submitted are revised from the limit order book while for large-cap stocks, these figures are approximately 32.8–38.6%. The ratios of revision and cancellation to limit order submission and to total order submission are much larger around the second ASX system upgrade on November 29th, 2010. Specifically, the ratios of revision limit order submission are nearly 85–110% for large-cap stocks and about 83–104% for small-cap stocks.[4] Furthermore, the revision ratio seems to be higher after the

[4] The ratio can exceed 100% due to the possibility of multiple revisions for each submission.

ASX system upgrade in 2010 for large-cap stocks but appears to be lower for small-cap stocks. On the other hand, for small-cap stocks one month after the system upgrade in 2006, the revision ratio is observed to be lower for buy orders but higher for sell orders. Meanwhile, for large-cap stocks, the revision ratio is generally lower for sell orders and mostly the same for buy orders. In contrast to the earlier sample documented by Liu (2009) and Fong and Liu (2010), cancellation ratios are small, as the predominant activities are order revisions. That said, cancellation rates are significantly higher after system upgrades.

3 Variable constructions and empirical model specification

3.1 Measure of the dynamic limit order placement activities (DLOPA)

In this study, we examine the dynamic activities of placing buy and sell limit orders of large-cap and small-cap stocks. Specifically, we focus on the order events of limit orders subsequent to its initial submission, namely revision, execution, and cancellation events of the order and its interaction with the market environment where the stock is traded. Following submission of a limit order to buy or sell a stock, if the order is not executed, the trader has the option to revise or cancel the order. The revised order can be left until being executed or it may also be revised again after the first revision. The activities of traders in managing their limit orders create a dynamic in the stock market.

Hasbrouck and Saar (2013) employ a time-weighting method to construct a *Run-In-Process* measure from the 'strategic runs'. We utilise a similar methodology akin to Hasbrouck and Saar (2013) to construct a measure of dynamic limit order placement activity (*DLOPA*) in order to explore its effect on the stock market quality. *DLOPA* is computed as the time-weighted average of the number of series of limit order events that have runs of 10 or more messages[5] the stock experiences in each 10-min interval.[6] If a run of a particular order starts from 10:01:00 and is active for the entire interval (10:00:00–10:10:00), it will have a value of 0.9 for the first interval (as it runs 90% of the 10-min interval). If it ends at 10:12:00, the run will receive a value of 0.9 (from prior interval) plus 0.2 which gives a value of 1.1.[7] Greater intensity of the dynamic activities that occur in a stock would give a higher value of *DLOPA*, and vice versa. By tracking the entire series of submissions, revisions, executions, and cancellations in a trading day for each stock, it is possible to examine the intensity of these dynamic activities and study their relation with the stock market environment where the orders are submitted.

[5] This definition is somewhat arbitrary. Hasbrouck and Saar (2013) argue that longer runs represent low-latency activity. For robustness, we include all runs with messages > 1. For example, a limit order submission that is followed by a full execution has the message of 1. If the order is revised once prior to its full execution, it has the message of 2. Unlike Hasbrouck and Saar (2013), we are utilising order book data that has a unique order identifier which allows us to track down the order events with no issue of misclassification, hence our measure of strategic runs is fairly accurate. Our conclusion, however, becomes less consistent with this new definition as it invariably inflates the value of DLOPA when limit orders stay in the book for a prolonged period of time. The introduction of noise to the measure makes it difficult to generate a sensible conclusion. A viable avenue for future research is to improve the measure by considering a different time-weighting mechanism given that our data contains a unique order identifier.

[6] Unlike Hasbrouck and Saar (2013) who impute links between cancellation and resubmission of orders based on how close between consecutive events (within 100 ms) where the orders matched with order types and size, SIRCA provides unique order identifiers which allows us to track the event sequence (submission, revision, cancellation or execution) of each order without error.

[7] For details of how the time-weighting is computed, see Footnote 16 of Hasbrouck and Saar (2013).

3.2 Constructions of market quality measures

In order to study how the market environment is affected by the limit order placement activities of traders, it is important to examine the changes in market quality throughout the periods of high and low intensity of activities. A number of market quality measures are constructed for the purpose of examining the relation between dynamic limit order placement activities and different aspects of the stock market quality. The first variable, *Volatility*, measures short-term volatility that the stock experiences in a certain time interval. It is computed as the difference between the highest and the lowest mid-point of the quoted bid/ask spreads in each 10-min interval. A lower (higher) value of *Volatility* means that the market is less (more) volatile and therefore the market experiences a higher (lower) quality.

$$Volatility_{i,t} = MaxMQ_{i,t} - MinMQ_{i,t} \tag{1}$$

The second variable, *QuoSprd*, measures the liquidity level that currently exists in the market. This variable is constructed as the time-weighted average of the quoted bid/ask spreads in each 10-min interval. A lower (higher) value of *QuoSprd* means that the market is more (less) liquid and hence a higher (lower) quality market.

$$QuoSprd_i = \frac{1}{n}\sum_{j=1}^{n}\left(T_{i,j+1} - T_{i,j}\right)_j\left(QuoAsk_{i,j} - QuoBid_{i,j}\right) \tag{2}$$

where $T_{i,j}$ is the time stamp of the *jth* quote update for stock i.

The third variable, *EffSprd*, also measures the level of liquidity in the market. However, *EffSprd* measures the total price impact of the trades, and the variable is calculated as the dollar-volume-weighted average of the effective spreads of the stock in each 10-min interval. The effective spread of a trade is defined as two times the absolute value of the difference between the transaction price (*TP*) and the prevailing mid-quote (*MQ*). A lower (higher) value of *EffSprd* means that the market is more (less) liquid and thus the market experiences a higher (lower) quality.

$$EffSprd_i = 2 \times \sum_{j=1}^{n}\left|TP_{i,j} - MQ_{i,j}\right| \tag{3}$$

The fourth variable is *LOBDepth* which measures the depth of the limit order book. This variable is another measure for market liquidity. It is computed as the time-weighted average of the number of shares up to 10 cents from the best-posted prices in the limit order book (buy-side and sell-side combined) in each 10-min interval. A higher (lower) value of *LOBDepth* means that the market is more (less) liquid and hence a higher (lower) quality market.

$$LOBDepth_i = \frac{1}{n}\sum_{j=1}^{n}\left(T_{i,j+1} - T_{i,j}\right)_j\left(LOBAsk_{i,j} + LOBBid_{i,j}\right) \tag{4}$$

where $T_{i,j}$ is the time stamp of the *jth* quote update for stock i.

Table 2 presents summary statistics of the variables employed in this study around the structural changes of the ASX.

3.3 Two-stage least squares

To study how technological improvements alter the impact of limit order placement activities on market quality, especially in the periods following the two structural changes: the launch

Table 2 Summary statistics of model variables

	Mean	SD	Median	P10	P90	N
Panel A: One month before the upgrade to ITS in 2006						
DLOPA	25.55	35.06	9.00	0.00	76.43	30,507
VOLATILITY ($)	0.148	9.539	0.015	0.000	0.095	30,636
EFFSPRD ($)	0.017	0.015	0.012	0.005	0.034	30,179
QUOSPRD ($)	0.010	0.023	0.005	0.003	0.016	23,870
LOBDEPTH (Shares)	869,610	3,196,203	139,586	18,286	1,011,384	30,636
Panel B: One month after the upgrade to ITS in 2006						
DLOPA	19.74	26.68	6.23	0.00	58.88	28,822
VOLATILITY ($)	0.086	6.596	0.020	0.000	0.095	28,908
EFFSPRD ($)	0.017	0.015	0.012	0.005	0.033	28,533
QUOSPRD ($)	0.009	0.024	0.005	0.003	0.015	23,607
LOBDEPTH (Shares)	1,065,196	4,231,031	137,896	18,470	1,341,824	28,908
Panel C: One month before the upgrade to ASX Trade in 2010						
DLOPA	87.49	89.64	56.15	3.26	220.60	31,675
VOLATILITY ($)	0.045	0.317	0.020	0.000	0.100	31,680
EFFSPRD ($)	0.011	0.004	0.010	0.005	0.016	30,052
QUOSPRD ($)	0.004	0.003	0.005	0.002	0.006	29,908
LOBDEPTH (Shares)	2,945,555	11,337,565	218,134	41,249	1,481,461	31,680
Panel D: One month after the upgrade to ASX Trade in 2010						
DLOPA	161.73	189.00	101.34	11.54	375.33	29,769
VOLATILITY ($)	0.039	0.426	0.010	0.000	0.080	31,680
EFFSPRD ($)	0.033	1.985	0.010	0.005	0.016	29,863
QUOSPRD ($)	0.005	0.004	0.005	0.002	0.006	27,438
LOBDEPTH (Shares)	2,439,371	9,504,904	188,052	35,037	1,484,750	31,680

This table presents the summary statistics for the variables used in the empirical model to study the relation between dynamic limit order placement activities and the stock market quality before and after the ASX system upgrade on 6th Oct 2006 and 29th Nov 2010. The measure used to study dynamic limit order placement activities is *DLOPA*. This is structured as the time-weighted average of the number of dynamic limit order placement activities that stock *i* has in each 10-min interval. *Volatility* measures the short-term volatility in the market. It is constructed as the difference between the highest and the lowest mid-point of the quoted bid/ask spreads in each 10-min interval. *QuoSprd* measures the level of liquidity currently existing in the market. This is computed as the time-weighted average of the quoted bid/ask spreads in each 10-min interval. *EffSprd* also measures the level of liquidity in the market. However, it is calculated as the dollar-volume-weighted average of the effective spreads of the stock in each 10-min interval. *LOBDepth* measures the depth of the limit order book and is computed as the time-weighted average of the number of shares of stock *i* in each 10-min interval. We report the mean, standard deviation (SD), median, the 10th percentile (P10) and the 90th percentile (P90) and the total number of observations for each variable

of ITS in 2006 and ASX Trade in 2010, which have significantly reduced the market latency of the ASX, we examine the order dynamics before and after the two events. Specifically, our pre-event (post-event) 2006 sample covers the period from September 5th, 2006 to October 5th, 2006 (October 7th, 2006 to November 7th, 2006). Our pre-event (post-event) 2010 sample covers the period from October 28th, 2010 to November 28th, 2010 (November 30th, 2010 to December 30th, 2010).

One of the key challenges is to address the possibility of endogeneity arising from simultaneity. A fall in liquidity may induce traders to act aggressively to supply liquidity, which may lead to an improvement in liquidity. This implies that regressing *DLOPA* against market quality using simple ordinary least squares (OLS) may lead to inconsistent estimates due to the potential correlation between *DLOPA* and the error term. To address the endogeneity concern, we follow Hasbrouck and Saar (2013) who generate an instrument for *DLOPA* by computing the time-weighted average of the number of series of limit order events that the *other* stocks in the sample (excluding stock *i*) experience in the same ten-minute intervals. For market quality measures, lagged values are used as instruments. We specify the following Two-Stage Least Squares (2SLS) involving estimation of the following set of equations:

$$MktQuality_{i,t} = \beta_{DLOPA} \times DLOPA_{i,t} + \beta_{MktQualIns} \times MktQualIns_{i,t} + \alpha \times Return_{i,t} + T_t + e_{mi,t} \quad (5)$$

$$DLOPA_{i,t} = \beta_{MktQuality} \times MktQuality_{i,t} + \beta_{DLOPAIns} \times DLOPAIns_{i,t} + \alpha \times Return_{i,t} + e_{di,t} \quad (6)$$

The model is estimated separately for each of the four market quality measures (short-term volatility, quoted spread, effective spread, and limit order book depth) using 2SLS. In Model (5), the endogenous variables $DLOPA_{i,t}$ in the first equation to be replaced by the fitted values of the regression of $DLOPA_{i,t}$ on the instrumental variables ($DLOPAIns_{i,t}$). This process provides a consistent estimate of the coefficient (β_{DLOPA}) which explains how dynamic limit order placement activities affect market quality. Similarly, the 2SLS method replaces $MktQuality_{i,t}$ in Model (6) with the fitted values of the regression of $MktQuality_{i,t}$ on the instrumental variables ($MktQualIns_{i,t}$). We include the average intra-period return for stock *i* in period *t* ($Return_{i,t}$) that may partially explain market quality, and period dummies (T_t) to capture intraday seasonality in market quality and DLOPA. For ease of interpretation, all variables are standardized. The estimations are conducted for the pooled sample of around the event, and separately, for the subsamples of large-cap stocks and small-cap stocks.

4 Empirical results

4.1 ASX system upgrade in 2006

Table 3 presents the estimation results for the sample around the 2006 system upgrade. The coefficient estimates are reported for each variable, together with their levels of significance. The standard errors are also included in the parentheses. The estimates of the coefficient β_{DLOPA} of the model (5) are presented separately for each of the market quality measures, including short-term volatility (*Volatility*), quoted spread (*QuoSprd*), effective spread (*EffSprd*), and depth of the limit order book (*LOBDepth*). Panel A presents the full sample, whereas Panels B and C present results of large-cap and small-cap stocks, respectively.

Prior to the 2006 system upgrade, an increase in dynamic limit order placement activities results leads to widening of the effective spread, but has negligible impact on the quoted spread, short-term volatility, or book-depth. After the system upgrade, market latency falls. With the exception of book-depth, the coefficients of all other market quality measures are positive and strongly significant. The size of the *EffSprd* estimated coefficient increases almost twofold from 0.051 to 0.094. As estimated coefficients of both the short-term volatility and

Table 3 Effects of dynamic limit order placement activities on market quality around the system upgrade from SEATS to ITS in 2006

Equation (5)	Pre (September 5th, 2006–October 5th, 2006)				Post (October 7th, 2006–November 7th, 2006)			
	Volatility	QuoSprd	EffSprd	LOBDepth	Volatility	QuoSprd	EffSprd	LOBDepth
Panel A: Full sample								
β_{DLOPA}	− 0.039 (0.054)	0.002 (0.026)	0.051*** (0.012)	0.003 (0.005)	0.002*** (0.000)	0.107*** (0.039)	0.094*** (0.020)	0.005 (0.010)
$\beta_{MktQualIns}$	0.015** (0.008)	0.637*** (0.006)	0.083*** (0.003)	1.004*** (0.002)	0.000 (0.000)	0.655*** (0.007)	0.061*** (0.003)	1.003*** (0.002)
Equation (6)	Pre (September 5th, 2006–October 5th, 2006)				Post (October 7th, 2006–November 7th, 2006)			
	Volatility	QuoSprd	EffSprd	LOBDepth	Volatility	QuoSprd	EffSprd	LOBDepth
$\beta_{MktQuality}$	1.280* (0.741)	− 0.054*** (0.012)	− 0.206** (0.103)	0.223*** (0.006)	− 6.407 (63.775)	− 0.180*** (0.008)	− 0.583*** (0.107)	0.188*** (0.003)
$\beta_{DLOPAIns}$	0.391*** (0.031)	0.375*** (0.013)	0.432*** (0.014)	0.389*** (0.013)	0.371*** (0.044)	0.390*** (0.014)	0.370*** (0.015)	0.407*** (0.012)
Equation (5)	Pre (September 5th, 2006–October 5th, 2006)				Post (October 7th, 2006–November 7th, 2006)			
	Volatility	QuoSprd	EffSprd	LOBDepth	Volatility	QuoSprd	EffSprd	LOBDepth
Panel B: Large-cap stocks								
β_{DLOPA}	− 0.033 (0.054)	0.017 (0.021)	0.048*** (0.011)	0.002 (0.005)	0.003*** (0.001)	0.179*** (0.069)	0.114*** (0.030)	0.009 (0.020)
$\beta_{MktQualIns}$	0.015 (0.009)	0.593*** (0.007)	0.078*** (0.003)	1.004*** (0.002)	0.000 (0.000)	0.638*** (0.012)	0.053*** (0.003)	1.002*** (0.004)
Equation (6)	Pre (September 5th, 2006–October 5th, 2006)				Post (October 7th, 2006–November 7th, 2006)			
	Volatility	QuoSprd	EffSprd	LOBDepth	Volatility	QuoSprd	EffSprd	LOBDepth
$\beta_{MktQuality}$	1.041 (0.729)	− 0.178*** (0.015)	− 0.341*** (0.108)	0.176*** (0.006)	− 14.614 (135.773)	− 0.239*** (0.011)	− 0.660*** (0.136)	0.184*** (0.004)
$\beta_{DLOPAIns}$	0.562*** (0.036)	0.554*** (0.015)	0.563*** (0.015)	0.558*** (0.014)	0.258** (0.115)	0.277*** (0.017)	0.284*** (0.018)	0.298*** (0.016)

Table 3 (continued)

Equation (5)	Pre (September 5th, 2006–October 5th, 2006)				Post (October 7th, 2006–November 7th, 2006)			
	Volatility	QuoSprd	EffSprd	LOBDepth	Volatility	QuoSprd	EffSprd	LOBDepth
Panel C: Small-cap stocks								
β_{DLOPA}	0.000 (0.000)	− 0.024 (0.069)	0.027 (0.053)	− 0.000 (0.002)	0.000** (0.000)	0.037 (0.040)	0.046** (0.023)	− 0.000 (0.001)
$\beta_{MktQualIns}$	0.402*** (0.011)	0.711*** (0.009)	0.172*** (0.011)	1.005*** (0.002)	0.504*** (0.012)	0.710*** (0.010)	0.278*** (0.015)	1.004*** (0.002)

Equation (6)	Pre (September 5th, 2006–October 5th, 2006)				Post (October 7th, 2006–November 7th, 2006)			
	Volatility	QuoSprd	EffSprd	LOBDepth	Volatility	QuoSprd	EffSprd	LOBDepth
$\beta_{MktQuality}$	− 8.560* (4.876)	− 0.008 (0.009)	0.071 (0.103)	0.337*** (0.057)	− 26.871*** (4.720)	− 0.090*** (0.010)	− 0.345*** (0.086)	1.102*** (0.071)
$\beta_{DLOPAIns}$	0.255*** (0.012)	0.254*** (0.012)	0.206*** (0.017)	0.255*** (0.012)	0.672*** (0.019)	0.670*** (0.019)	0.687*** (0.025)	0.681*** (0.018)

This table presents the empirical results for the study of dynamic limit order placement activities and how they affect stock market quality during the period around the launch of ITS on October 6th, 2006. *Volatility* measures the short-term volatility in the market. *QuoSprd* measures the level of liquidity, calculated as the time-weighted average of the quoted bid/ask spreads. *EffSprd* also measures the level of liquidity but is calculated as the dollar-volume-weighted average of the effective spreads. *LOBDepth* measures the depth of the limit order book, computed as the time-weighted average of the number of shares in the limit order book. The measure used to study dynamic limit order placement activities is *DLOPA*, structured as the time-weighted average of the number of dynamic limit order placement activities that stock i has in each 10-min interval. The empirical model employs two instrumental variables for market quality and dynamic limit order placement activities, namely, *MktQualIns* and *DLOPAIns* respectively. *Return* is the average intra-period trade return. The coefficient estimates are presented for each of the variables and the standard errors are reported in the parentheses. ***, **, * denote statistical significance at the 1, 5, and 10 percent level, respectively. Time-fixed effects are included. The following model of two simultaneous equations is estimated separately for each of the market quality measures, using Two-Stage-Least-Squares:

$$MktQuality_{i,t}= \beta_{DLOPA} \times DLOPA_{i,t}+ \beta_{MktQualIns} \times MktQualIns_{i,t}+ \alpha \times Return_{i,t} +T_t +e_{mi,t} \quad (5)$$

$$DLOPA_{i,t}= \beta_{MktQuality} \times MktQuality_{i,t}+ \beta_{DLOPAIns} \times DLOPAIns_{i,t}+ \alpha \times Return_{i,t} +T_t +e_{di,t} \quad (6)$$

the cost of liquidity measure heighten, our pooled sample results seem to indicate post-ASX's migration to ITS associated with worsening market quality.

Estimates of Model (6) reveal an interesting dynamic. Prior to the system upgrade, the coefficient $\beta_{MktQuality}$ is negative and statistically significant for both spread measures, positive and statistically significant for book-depth. When liquidity dries up, AT/HFT activities (captured by DLOPA) fall. When liquidity improves, dynamic trading activities increases as AT/HFT traders move in to demand liquidity, thereby causing the spread to increase (see Model (5)). This is particularly true after latency is reduced, as lower latency provides better capacity for AT/HFT traders to take liquidity promptly when it is cheap.

Panel B of Table 3 presents the result of large-cap stocks. Overall, the results are similar to the pooled sample. The effect of lower market latency leads to more than double the size of the estimated coefficient of *EffSprd* in Model (5). The impact of dynamic trading activity has increased short-term volatility moderately. Results from small-cap stocks (Panel C) show fairly consistent results for Model (5) where lower latency induces AT/HFT to partake and drive up the trading cost (significantly positive β_{DLOPA} for *EffSprd*). Model (6) shows that among small-cap stocks, dynamic limit order placement activities and market quality relation evolve from not significant at all (prior to the ITS adoption) to negatively and strongly significant (after the ITS adoption) in both the volatility and spread measures, and positively and strongly significant in the book depth. This result implies that a high-quality market environment encourages a higher level of limit order activities. Traders are more motivated to revise limit orders (perhaps to market orders) when the market is less volatile and has a high liquidity level. The lower latency also helps AT/HFT traders to position themselves to take advantage of small stocks liquidity when it is relatively cheap. This result contradicts the finding of Riordan and Storkenmaier (2012) who find that reduced latency improves liquidity mostly in small and medium-sized stocks.

4.2 ASX system upgrade in 2010

Table 4 presents the estimation results for the sample around the 2010 system upgrade from ITS to ASX Trade. After the system upgrade, market latency falls further, with an increase in trading activities led by AT/HFT demonstrated by a twofold increase in DLOPA (see Table 2 Panel D). Panel A of Table 4 shows the result of the pooled sample, which reveals a mixed picture. Comparing to Table 3, the estimated coefficient of *EffSprd* in Model (5) is negative and significant prior to the upgrade, and it becomes positive after the upgrade, while the estimated coefficient of *LOBDepth* turns from insignificant to negative and marginally significant. When we separate the sample into large-cap stocks and small-cap stocks, a consistent pattern emerges. The negative (and strongly significant) coefficient of *QuoSprd* in large-cap stocks and the positive (and strongly significant) coefficient of *EffSprd* in small-cap stocks after the system upgrade seems to suggest that the benefits of lower latency depend on the interplay of competition among liquidity providers. AT/HFT tends to *provide* liquidity in large-cap stocks (Menkveld, 2013), as the technological upgrade creates a superior platform for AT/HFT to engage aggressively. The opposite appears to be true for small-cap stocks, as AT/HFT tends to *demand* liquidity; as DLOPA increases, spread increases. For both small and large-cap stocks, DLOPA do not appear to have significant impact on the depth of the limit order book. Dynamic limit order placement activities appear to have a stabilising effect on large stocks as the estimated coefficients of short-term volatility are negative, both before and after the upgrade, with threefold increase in absolute term post-system upgrade.

Table 4 Effects of dynamic limit order placement activities on market quality around the system upgrade from ITS to ASX trade in 2010

Equation (5)	Pre (October 28th, 2010–November 28th, 2010)				Post (November 30th, 2010–December 30th, 2010)			
	Volatility	QuoSprd	EffSprd	LOBDepth	Volatility	QuoSprd	EffSprd	LOBDepth
Panel A: Full sample								
β_{DLOPA}	− 0.120*** (0.022)	− 0.075 (0.049)	− 0.038** (0.019)	0.004 (0.016)	− 0.085*** (0.006)	− 0.038** (0.016)	0.023*** (0.007)	− 0.007* (0.004)
$\beta_{MktQualIns}$	0.031*** (0.001)	0.814*** (0.006)	0.018*** (0.001)	1.006*** (0.002)	0.014*** (0.001)	0.759*** (0.003)	0.038*** (0.001)	1.006*** (0.001)
Equation (6)	Pre (October 28th, 2010–November 28th, 2010)				Post (November 30th, 2010–December 30th, 2010)			
	Volatility	QuoSprd	EffSprd	LOBDepth	Volatility	QuoSprd	EffSprd	LOBDepth
$\beta_{MktQuality}$	0.468*** (0.180)	0.130*** (0.007)	0.647** (0.262)	0.086*** (0.004)	0.256 (0.325)	0.103*** (0.009)	0.228 (0.154)	0.133*** (0.006)
$\beta_{DLOPAIns}$	0.187*** (0.018)	0.197*** (0.018)	0.183*** (0.018)	0.183*** (0.017)	0.399*** (0.017)	0.386*** (0.013)	0.378*** (0.013)	0.395*** (0.012)
Equation (5)	Pre (October 28th, 2010–November 28th, 2010)				Post (November 30th, 2010–December 30th, 2010)			
	Volatility	QuoSprd	EffSprd	LOBDepth	Volatility	QuoSprd	EffSprd	LOBDepth
Panel B: Large-cap stocks								
β_{DLOPA}	− 0.018** (0.008)	− 0.013 (0.024)	− 0.005 (0.007)	0.001 (0.006)	− 0.066*** (0.005)	− 0.044*** (0.012)	− 0.001 (0.003)	− 0.005 (0.003)
$\beta_{MktQualIns}$	0.020*** (0.001)	0.722*** (0.006)	0.007*** (0.001)	1.004*** (0.002)	0.009*** (0.001)	0.622*** (0.006)	0.011*** (0.001)	1.007*** (0.002)
Equation (6)	Pre (October 28th, 2010–November 28th, 2010)				Post (November 30th, 2010–December 30th, 2010)			
	Volatility	QuoSprd	EffSprd	LOBDepth	Volatility	QuoSprd	EffSprd	LOBDepth
$\beta_{MktQuality}$	− 0.889*** (0.235)	− 0.208*** (0.010)	− 0.730 (0.676)	0.310*** (0.006)	− 0.921** (0.372)	− 0.294*** (0.015)	− 0.458 (0.539)	0.376*** (0.007)
$\beta_{DLOPAIns}$	0.637*** (0.022)	0.628*** (0.022)	0.645*** (0.023)	0.698*** (0.021)	0.743*** (0.025)	0.753*** (0.016)	0.788*** (0.016)	0.819*** (0.014)

Table 4 (continued)

Equation (5)	Pre (October 28th, 2010–November 28th, 2010)				Post (November 30th, 2010–December 30th, 2010)			
	Volatility	QuoSprd	EffSprd	LOBDepth	Volatility	QuoSprd	EffSprd	LOBDepth
Panel C: Small-cap stocks								
β_{DLOPA}	0.030 (0.147)	0.107 (0.902)	1.199 (1.925)	– 0.042 (0.414)	0.000 (0.006)	0.035 (0.054)	0.183*** (0.036)	– 0.022 (0.016)
$\beta_{MktQualIns}$	0.551*** (0.122)	0.825*** (0.105)	0.073 (0.047)	1.000*** (0.012)	0.397*** (0.009)	0.799*** (0.010)	0.128*** (0.004)	1.001*** (0.001)

Equation (6)	Pre (October 28th, 2010–November 28th, 2010)				Post (November 30th, 2010–December 30th, 2010)			
	Volatility	QuoSprd	EffSprd	LOBDepth	Volatility	QuoSprd	EffSprd	LOBDepth
$\beta_{MktQuality}$	– 1.579*** (0.143)	– 0.143*** (0.008)	– 0.536*** (0.181)	– 0.028*** (0.004)	– 3.144*** (0.220)	– 0.206*** (0.009)	– 0.356*** (0.074)	– 0.031*** (0.006)
$\beta_{DLOPAIns}$	0.009 (0.017)	0.013 (0.017)	0.018 (0.017)	0.010 (0.017)	0.129*** (0.012)	0.141*** (0.012)	0.144*** (0.013)	0.142*** (0.012)

This table presents the empirical results for the study of dynamic limit order placement activities and how they affect stock market quality during the period around the launch of ASX Trade on November 29th, 2010. *Volatility* measures the short-term volatility in the market. *QuoSprd* measures the level of liquidity, calculated as the time-weighted average of the quoted bid/ask spreads. *EffSprd* also measures the level of liquidity but is calculated as the dollar-volume-weighted average of the effective spreads. *LOBDepth* measures the depth of the limit order book, computed as the time-weighted average of the number of shares in the limit order book. The measure used to study dynamic limit order placement activities is *DLOPA*, structured as the time-weighted average of the number of dynamic limit order placement activities that stock *i* has in each 10-min interval. The empirical model employs two instrumental variables for market quality and dynamic limit order placement activities, namely, *MktQualIns* and *DLOPAIns* respectively. *Return* is the average intra-period trade return. The coefficient estimates are presented for each of the variables and the standard errors are reported in the parentheses. ***, **, * denote statistical significance at the 1, 5, and 10 percent level, respectively. Time-fixed effects are included. The following model of two simultaneous equations is estimated separately for each of the market quality measures, using Two-Stage-Least-Squares:

$MktQuality_{i,t} = \beta_{DLOPA} \times DLOPA_{i,t} + \beta_{MktQualIns} \times MktQualIns_{i,t} + \alpha \times Return_{i,t} + T_t + e_{mi,t}$ (5)

$DLOPA_{i,t} = \beta_{MktQuality} \times MktQuality_{i,t} + \beta_{DLOPAIns} \times DLOPAIns_{i,t} + \alpha \times Return_{i,t} + T_t + e_{di,t}$ (6)

Contrasting to Table 3, Model (6) presents the opposite dynamic. The positive relation between quoted spread and DLOPA seems to suggest as spread rises, traders respond by increasing their order placement activities, including revising their submitted orders to compete for liquidity provision. This is consistent with the previous literature where traders become more aggressive when the spread is wider, and the temporary volatility is higher (Ranaldo, 2004). Positive and significant coefficient of *LOBDepth* may imply that a deep order book depth lowers execution probability, hence causes traders to revise and position their orders to improve execution probability. This is largely the case among large-cap stocks (Panel B) where competition for liquidity provision is intense. For small-cap stocks (Panel C), system upgrade does not appear to alter the behaviour of dynamic limit order placement significantly. As spread falls, DLOPA rises as traders compete to benefit from lower spread. Surprisingly, when the short-term volatility heightens, DLOPA falls. This somewhat contradicts to our preconception that as the market becomes more turbulent, traders would engage actively to reduce adverse selection risk.

Overall, our empirical results indicate that dynamic limit order activities respond to stock market conditions. As these activities intensify, they in turn affect the quality of the market. When the market turns more volatile or becomes less liquid, traders increase their frequencies in revising or cancelling their submitted limit orders. These responses are carried out by traders in an attempt to improve execution quality and reduce transaction costs. As the level of dynamic limit order activities rises, more liquidity is provided to the market and the volatility is lowered. Therefore, it results in an improvement of quality for the market where the stock is traded.

However, we find little evidence suggesting that the move to a lower latency environment leads to significant improvement of market quality. This finding is, in fact, consistent with Gai et al. (2013) who report that an increase in the speed of trading from microseconds to nanoseconds does not lead to improvements on quoted spread, effective spread, trading volume and variance ratio.

4.3 Robustness checks

We perform robustness tests of our baseline pooled sample. One might argue that the event window (1 day) is too short to establish any material impact on the interactions between dynamic limit order placement activities and market quality. For robustness, we reproduce the pooled sample result by extending the event window from 1 day to 2 months.

In Panel A of Table 5, we present the baseline pooled sample result for comparison, which is essentially the same as in Panel A of Table 3 where the event window is 1 day. In Panel B, we expand the event window to 2 months, with the pre-event (post-event) window covers the period from August 6th, 2006 to September 5th, 2006 (November 7th, 2006 to December 6th, 2006). Similar to the baseline result, only the estimated coefficient of β_{DLOPA} on *QuoSprd* in Model (5) is positive and statistically significant prior to the system upgrade. The size of the coefficient is 4 times larger with a wider event window, in part due to lower DLOPA further away from the event date (1 month as opposed to 1 day prior to the event). After the event, β_{DLOPA} coefficient estimates on both spread measures (*QuoSprd* and *EffSprd*) are positive and statistically significant, albeit smaller in size, which may be due to higher DLOPA with improved technology further away from the event date.

Interestingly, the impact of market quality on DLOPA changes markedly before and after the event. Prior to the event, Model (6) shows that the coefficients on the spread measure are positive and significant (as opposed to positive at baseline), and they switch to negative

Table 5 Effects of dynamic limit order placement activities on market quality around the system upgrade from SEATS to ITS in 2006 (Wider event window)

Equation (5)	Pre (September 5th, 2006–October 5th, 2006)				Post (October 7th, 2006–November 7th, 2006)			
	Volatility	QuoSprd	EffSprd	LOBDepth	Volatility	QuoSprd	EffSprd	LOBDepth
Panel A: Baseline (with event window of one day)								
β_{DLOPA}	− 0.039 (0.054)	0.002 (0.026)	0.051*** (0.012)	0.003 (0.005)	0.002*** (0.000)	0.107*** (0.039)	0.094*** (0.020)	0.005 (0.010)
$\beta_{MktQualIns}$	0.015** (0.008)	0.637*** (0.006)	0.083*** (0.003)	1.004*** (0.002)	0.000 (0.000)	0.655*** (0.007)	0.061*** (0.003)	1.003*** (0.002)
Equation (6)	Pre (September 5th, 2006–October 5th, 2006)				Post (October 7th, 2006–November 7th, 2006)			
	Volatility	QuoSprd	EffSprd	LOBDepth	Volatility	QuoSprd	EffSprd	LOBDepth
$\beta_{MktQuality}$	1.280* (0.741)	− 0.054*** (0.012)	− 0.206** (0.103)	0.223*** (0.006)	− 6.407 (63.775)	− 0.180*** (0.008)	− 0.583*** (0.107)	0.188*** (0.003)
$\beta_{DLOPAIns}$	0.391*** (0.031)	0.375*** (0.013)	0.432*** (0.014)	0.389*** (0.013)	0.371*** (0.044)	0.390*** (0.014)	0.370*** (0.015)	0.407*** (0.012)
Equation (5)	Pre (August 6th, 2006–September 5th, 2006)				Post (November 7th, 2006–December 6th, 2006)			
	Volatility	QuoSprd	EffSprd	LOBDepth	Volatility	QuoSprd	EffSprd	LOBDepth
Panel B: Wider event window (two months)								
β_{DLOPA}	0.571 (7.437)	− 3.929 (11.439)	0.220*** (0.054)	− 0.220 (4.633)	0.003*** (0.000)	0.077*** (0.024)	0.059*** (0.011)	0.001 (0.005)
$\beta_{MktQualIns}$	− 0.098 (1.358)	1.139 (1.277)	0.051*** (0.003)	1.013*** (0.188)	0.064*** (0.002)	0.691*** (0.004)	0.055*** (0.002)	1.005*** (0.001)
Equation (6)	Pre (August 6th, 2006–September 5th, 2006)				Post (November 7th, 2006–December 6th, 2006)			
	Volatility	QuoSprd	EffSprd	LOBDepth	Volatility	QuoSprd	EffSprd	LOBDepth
$\beta_{MktQuality}$	27.424*** (8.259)	0.159*** (0.009)	0.303** (0.142)	0.040*** (0.006)	3.597** (1.800)	− 0.021*** (0.006)	− 0.146* (0.085)	0.119*** (0.004)
$\beta_{DLOPAIns}$	− 0.020 (0.019)	− 0.010 (0.018)	0.138*** (0.023)	0.001 (0.018)	0.356*** (0.010)	0.362*** (0.009)	0.409*** (0.011)	0.362*** (0.009)

This table presents robustness tests for the sample period around the launch of ITS in 2006. Panel A presents the baseline results from the pooled sample in Table 3. Panel B presents the results based on a wider event window (two months instead of one day). See Table 3's captions for the definition of variables and the model specification.

and statistically significant after the event (which is consistent with the baseline result). This result seems to suggest that prior to the upgrade, activities intensify to provide liquidity when the spread is high. After the upgrade, more order book activities imply that more liquidity provision, hence when the spread is small, AT/HFT traders demand liquidity, thereby causing the spread to increase.

In Table 6, we present the robustness check on Table 4's results. Panel B shows a consistent pattern, but with reduced significance, where both spread measures in Model (5) are insignificant after the upgrade. With a wider event window, the impact of DLOPA on market quality generally falls as the market equilibrates—the impact of technology upgrade yields negligible impact as AT/HFT matures. They compete intensely for liquidity provision, while at the same time demand liquidity when it is cheap. Over time, the net impact of DLOPA on market quality becomes insignificant. Results from Model (6) in Panel B show fairly consistent results compared to the baseline.

5 Conclusion

Limit order revision and cancellation activities have been documented in recent studies to play an important role in setting dynamic limit order placement strategies. However, the existing theoretical and empirical research in the market microstructure literature has not adequately accounted for the effects of order placement activities on the quality of stock markets when traders dynamically revise or cancel their buy/sell limit orders. We construct measures of dynamic limit order placement activities that encapsulate a complete sequence of order submission, revision, execution as well as cancellation of each order. We examine its interaction with the market quality in the setting of a lower latency trading environment.

We show that traders dynamically manage their order placement activities in an attempt to respond to certain stock market conditions. Specifically, when the market becomes less volatile or more liquid, traders are more motivated to intensify their order placement activities, including revising or cancelling their submitted limit orders. When we examine the ASX system upgrade in 2006, we find evidence suggesting that lower latency helps AT/HFT traders to position themselves to take advantage of small stocks' liquidity when it is relatively cheap.

This harmful effect, however, reverses after the second upgrade where latency was further reduced. When the ASX moves from ITS to ASX Trade, we find evidence suggesting that in large-cap stocks, AT/HFTs provide liquidity and stabilise the price when short-term volatility is high, though they continue to demand liquidity in small-cap stocks. We conclude that, as technology improves and market latency falls, the adverse influences of the order placement activities fall. The network effect of liquidity outweighs as AT/HFTs traders compete to provide liquidity.

A lower latency trading environment provides means for more developments of technology and efficient trading algorithms. Nevertheless, an AT/HFT arms race could backfire and create disastrous events such as the stock market flash crash on May 6th, 2010. The findings of this study are beneficial for both academics and stock market participants in enhancing understanding of the effectiveness of dynamic limit order placement strategies. This research also offers stock exchange regulators a framework where the balance of costs and benefits of order placement activities can be weighted before appropriate regulations could be set for a more efficiently functioning stock exchange. Since our results indicate that AT/HFT could present a risk to market quality, regulators need to put great efforts to collect information in order to decide on potentially new provisions which might become necessary if this problem

Table 6 Effects of dynamic limit order placement activities on market quality around the system upgrade from ITS to ASX trade in 2010 (Wider event window)

Equation (5)	Pre (October 28th, 2010–November 28th, 2010)				Post (November 30th, 2010–December 30th, 2010)			
	Volatility	QuoSprd	EffSprd	LOBDepth	Volatility	QuoSprd	EffSprd	LOBDepth
Panel A: Baseline (with event window of one day)								
β_{DLOPA}	– 0.120*** (0.022)	– 0.075 (0.049)	– 0.038** (0.019)	0.004 (0.016)	– 0.085*** (0.006)	– 0.038** (0.016)	0.023*** (0.007)	– 0.007* (0.004)
$\beta_{MktQualIns}$	0.031*** (0.001)	0.814*** (0.006)	0.018*** (0.001)	1.006*** (0.002)	0.014*** (0.001)	0.759*** (0.003)	0.038*** (0.001)	1.006*** (0.001)
Equation (6)	Pre (October 28th, 2010–November 28th, 2010)				Post (November 30th, 2010–December 30th, 2010)			
	Volatility	QuoSprd	EffSprd	LOBDepth	Volatility	QuoSprd	EffSprd	LOBDepth
$\beta_{MktQuality}$	0.468*** (0.180)	0.130*** (0.007)	0.647** (0.262)	0.086*** (0.004)	0.256 (0.325)	0.103*** (0.009)	0.228 (0.154)	0.133*** (0.006)
$\beta_{DLOPAIns}$	0.187*** (0.018)	0.197*** (0.018)	0.183*** (0.018)	0.183*** (0.017)	0.399*** (0.017)	0.386*** (0.013)	0.378*** (0.013)	0.395*** (0.012)
Equation (5)	Pre (August 29th, 2010–September 28th, 2010)				Post (December 30th, 2010–January 29th, 2011)			
	Volatility	QuoSprd	EffSprd	LOBDepth	Volatility	QuoSprd	EffSprd	LOBDepth
Panel B: Wider event window (two months)								
β_{DLOPA}	– 0.042*** (0.007)	– 0.000 (0.000)	– 0.121* (0.073)	0.001 (0.016)	– 0.024*** (0.003)	– 0.000 (0.020)	0.017 (0.031)	– 0.008* (0.004)
$\beta_{MktQualIns}$	0.032*** (0.001)	0.811*** (0.007)	0.257*** (0.004)	1.006*** (0.001)	0.014*** (0.001)	0.798 (1.003)	0.303*** (0.004)	1.008*** (0.002)
Equation (6)	Pre (August 29th, 2010–September 28th, 2010)				Post (December 30th, 2010–January 29th, 2011)			
	Volatility	QuoSprd	EffSprd	LOBDepth	Volatility	QuoSprd	EffSprd	LOBDepth
$\beta_{MktQuality}$	1.955*** (0.400)	28.117*** (0.858)	0.122*** (0.014)	0.004 (0.003)	4.125*** (1.486)	52.057 (39.471)	0.086*** (0.023)	0.357*** (0.007)
$\beta_{DLOPAIns}$	0.215*** (0.016)	0.231*** (0.016)	0.246*** (0.016)	0.198*** (0.016)	0.295*** (0.017)	0.259 (0.266)	0.281*** (0.016)	0.284*** (0.014)

This table presents robustness tests for the sample period around the launch of ITS in 2006. Panel A presents the baseline results from the pooled sample in Table 4. Panel B presents the results based on a wider event window (two months instead of one day). See Table 4's captions for the definition of variables and the model specification.

arises. Furthermore, given the market quality could be negatively affected after a system upgrade, regulators need to be enabled for near-time reactions and rapid investigations in case of market stress. Policymakers need to keep an eye on the impact of AT/HFT on the market quality or integrity by maintaining contact with the different and evolving market participants, for instance, through the participation of policymakers in the foreign exchange committees in a range of jurisdictions (Debelle, 2011). Overall, since AT/HFT is a relatively new phenomenon in securities markets, it is recommended that ASIC, as the country's main financial regulator, needs to take a proactive role in articulating what is deemed to be acceptable and unacceptable algorithmic trading practices.

References

Ahn, H. J., Bae, K. H., & Chan, K. (2001). Limit orders, depth and volatility: Evidence from the stock exchange of Hong Kong. *Journal of Finance, 56*(2), 767–788. https://doi.org/10.1111/0022-1082.00345

Bacidore, J., Battalio, R., & Jennings, R. (2003). Order submission strategies, liquidity supply, and trading in pennies on the New York Stock Exchange. *Journal of Financial Markets, 6*(3), 337–362. https://doi.org/10.1016/S1386-4181(03)00003-X

Brogaard, J., Hagströmer, B., Nordén, L., & Riordan, R. (2015). Trading fast and slow: Colocation and liquidity. *The Review of Financial Studies, 28*(12), 3407–3443. https://doi.org/10.1093/rfs/hhv045

Buti, S., & Rindi, B. (2013). Undisclosed orders and optimal submission strategies in a limit order market. *Journal of Financial Economics, 109*(3), 797–812. https://doi.org/10.1016/j.jfineco.2013.04.002

Cao, C., Hansch, O., & Wang, X. (2008). Order placement strategies in a pure limit order book market. *Journal of Financial Research, 31*(2), 113–140. https://doi.org/10.1111/j.1475-6803.2008.00234.x

Cohen, K. J., Maier, S. F., Schwartz, R. A., & Whitcomb, D. K. (1981). Transaction costs, order placement strategy, and existence of the bid-ask spread. *Journal of Political Economy, 89*(2), 287–305. https://doi.org/10.1086/260966

Cont, R., & Kukanov, A. (2017). Optimal order placement in limit order markets. *Quantitative Finance, 17*(1), 21–39. https://doi.org/10.1080/14697688.2016.1190030

Easley, D., Hendershott, T., & Ramadorai, T. (2014). Leveling the trading field. *Journal of Financial Markets, 17*, 65–93. https://doi.org/10.1016/j.finmar.2013.06.003

Fong, K., & Liu, W. M. (2010). Limit order revisions. *Journal of Banking and Finance, 34*(8), 1873–1885. https://doi.org/10.1016/j.jbankfin.2009.12.010

Frino, A., Lepone, A., & Mistry, M. (2011). *The new breed of Market Participants: High frequency trading: Evidence from the Australian Stock Exchange*. Discipline of Finance, University of Sydney. Working Paper.

Fung, W., & Hsieh, D. A. (1997). Empirical characteristics of dynamic trading strategies: The case of hedge funds. *Review of Financial Studies, 10*(2), 275–302. https://doi.org/10.1093/rfs/10.2.275

Gai, J., Ye, M. & Yao, C. (2013). The externalities of high frequency trading. *WBS Finance Group Research Paper*.

Guy, D. (2011). *High frequency trading in foreign exchange markets*. Bank for International Settlements (BIS). BIS Working Group. Available at: https://www.bis.org/review/r111013e.pdf

Harris, L., & Hasbrouck, J. (1996). Market vs. limit orders: The SuperDot evidence on order submission strategy. *Journal of Financial and Quantitative Analysis, 31*(2), 213–231. https://doi.org/10.2307/2331180

Hasbrouck, J., & Saar, G. (2013). Low-latency trading. *Journal of Financial Markets, 16*(4), 646–679. https://doi.org/10.1016/j.finmar.2013.05.003

Hendershott, T., & Moulton, P. C. (2011). Automation, speed, and stock market quality: The NYSE's hybrid. *Journal of Financial Markets, 14*(4), 568–604. https://doi.org/10.1016/j.finmar.2011.02.003

Jain, P. K., Jain, P., & McInish, T. H. (2016). Does high-frequency trading increase systemic risk? *Journal of Financial Markets, 31*, 1–24. https://doi.org/10.1016/j.finmar.2016.09.004

Kissell, R., Glantz, M., & Malamut, R. (2004). A practical framework for estimating transaction costs and developing optimal trading strategies to achieve best execution. *Finance Research Letters, 1*(1), 35–46. https://doi.org/10.1016/S1544-6123(03)00004-7

Le, A. T., Le, T. H., Liu, W. M., & Fong, K. Y. (2020). Multiple duration analyses of dynamic limit order placement strategies and aggressiveness in a low-latency market environment. *International Review of Financial Analysis, 72*, 101575. https://doi.org/10.1016/j.irfa.2020.101575

Le, A. T., Le, T. H., Liu, W. M., & Fong, K. Y. (2021). Dynamic limit order placement strategies: Survival analysis with a multiple-spell duration model. *Annals of Operations Research, 297*, 241–275. https://doi.org/10.1007/s10479-019-03384-y

Liu, W.-M. (2009). Monitoring and limit order submission risks. *Journal of Financial Markets, 12*(1), 107–141. https://doi.org/10.1016/j.finmar.2008.04.003

Lo, A. W., MacKinlay, A. C., & Zhang, J. (2002). Econometric models of limit order executions. *Journal of Financial Economics, 65*(1), 31–71. https://doi.org/10.1016/S0304-405X(02)00134-4

Menkveld, A. J. (2013). High frequency trading and the new market makers. *Journal of Financial Markets, 16*(4), 712–740. https://doi.org/10.1016/j.finmar.2013.06.006

Murray, H., Pham, T. P., & Singh, H. (2016). Latency reduction and market quality: The case of the Australian Stock Exchange. *International Review of Financial Analysis, 46*, 257–265. https://doi.org/10.1016/j.irfa.2015.09.001

Parlour, C. (1998). Price dynamics in limit order markets. *Review of Financial Studies, 11*(4), 789–816. https://doi.org/10.1093/rfs/11.4.789

Ranaldo, A. (2004). Order aggressiveness in limit order markets. *Journal of Financial Markets, 7*(1), 53–74. https://doi.org/10.1016/S1386-4181(02)00069-1

Riordan, R., & Storkenmaier, A. (2012). Latency, liquidity and price discovery. *Journal of Financial Markets, 15*(4), 416–437. https://doi.org/10.1016/j.finmar.2012.05.003

Van Ness, B. F., Van Ness, R. A., & Watson, E. D. (2015). Canceling liquidity. *Journal of Financial Research, 38*(1), 3–33. https://doi.org/10.1111/jfir.12051

Yamamoto, R. (2020). Limit order submission risks, order choice, and tick size. *Pacific-Basin Finance Journal, 59*, 101261. https://doi.org/10.1016/j.pacfin.2019.101261