Dynamic order placement strategies and stock market quality: further evidence from a new approach

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Dynamic Order Placement Strategies and Stock Market Quality: Further Evidence from a New Approach

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A dissertation submitted to the University of New South Wales in fulfilment of the requirements for the degree of Doctor of Philosophy (PhD)

Banking and Finance

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ORIGINALITY STATEMENT

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ABSTRACT

Recent studies have documented that limit order revision and cancellation activities play an important role in creating dynamic order placement strategies. By utilising a new approach, this thesis provides further evidence on order placement strategies, their determinants and their effects on the quality of the stock market.

Firstly, this thesis constructs the full life for each limit order as a series of successive order events. Survival analyses with both single-spell duration and multiple-spell duration models are employed to examine the determinants of dynamic limit order placement strategies in the Australian Securities Exchange (ASX). This thesis is, perhaps, the first study which employs such a new approach in this area of research. Limit order placement strategies are found to be determined by the limit order characteristics, by the conditions of the stock market where the limit order is placed, as well as by the previous duration of the limit order.

Secondly, this thesis creates a measure for dynamic limit order placement activities and examines how these activities affect the quality of the stock market. Using a system of simultaneous equations, the thesis finds that order placement activities are increased in response to market turbulence such as heightened volatility and reduced liquidity. The results suggest that the quality of the stock market is significantly improved as traders intensify their activities, including the activities of revising or cancelling their limit orders. However, this positive effect is only found in the early period before the structural changes of the ASX. Following ASX's migrations to lower-latency exchanges, the intensity of order placement activities tends to reduce the quality of the stock market.

Thirdly, this thesis investigates dynamic limit order placement strategies and their aggressiveness in a low-latency market environment. The study employs a new approach with a multiple-spell duration model to examine the factors that contribute to the decision of traders to cancel or revise limit orders, as well as the decision to opt for an aggressive or a defensive strategy. The results provide evidence in support for both the ‘chasing hypothesis’ and the ‘cost of immediacy hypothesis’ of limit orders.

The findings of this thesis are significant not only for researchers, but also for market regulators as well as other stock market participants.

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LIST OF ABBREVIATIONS

ASX	Australian Securities Exchange
DAX	German Stock Market Index (*Deutscher Aktien Index*)
ECN	Electronic Communication Network
ITS	Integrated Trading System
LSE	London Stock Exchange
NASDAQ	National Association of Securities Dealers Automated Quotations
NYSE	New York Stock Exchange
SEATS	Stock Exchange Automated Trading System
SIRCA	Securities Industry Research Centre of Asia-Pacific

CHAPTER 1

INTRODUCTION

1.1. Research Motivation

Limit order duration has been regarded in the recent period as being highly important when evaluating order placement strategies. It has also been revealed that a significant number of limit orders submitted on the world's largest stock exchanges, including the New York Stock Exchange (NYSE), the London Stock Exchange (LSE) and the Australian Securities Exchange (ASX), are revised or cancelled (see, for example, Coppejans and Domowitz, 2002; Yeo, 2006; Fong and Liu, 2010). Given the drastic transformation of the trading industry in recent years, limit order revision and cancellation activities have been growing in popularity and they have become an important part of order placement strategies. However, studies which thoroughly examine the duration of these activities are very limited in the literature. Most of the previous research on duration analysis has focused on the time-to-execution and largely ignored the time-to-revision and time-to-cancellation. In the more recent studies, the role of limit order cancellations starts to attract some attention (see, for example, Hasbrouck and Saar, 2009). As a result, it is essential to take into consideration limit order revision and cancellation as an important part of dynamic strategies in studying their effects on securities markets.

To better understand dynamic order placement strategies, their determinants and effects, it is important to understand the duration of order events as well as the multiple events that occur within the life of each limit order. The vast majority of the existing studies in the literature only provide analyses using single duration models which mainly concern with the time-to-execution (see, for example, Lo et al., 2002). This existing approach is unable to adequately take into account all series of successive limit order events and the factors that determine the occurrence of these events. As a result, a more suitable method is an approach that employs survival analysis with a multiple-spell duration model to examine the determinants that affect the multiple order events in the whole life of a limit order. In fact, there are methods that have been applied broadly in the literature of labour economics which could help fill this gap in the finance literature. To the best of my knowledge, this thesis is the first study that utilises the new approach of employing both single-spell and multiple-spell duration models to study dynamic limit order placement strategies where order revisions and cancellations are also examined as active events of order placement activities.

1.2. Objectives and Main Findings of the Thesis

Chapter 3 examines the determinants of dynamic limit order placement strategies and expands the existing studies in the current literature by incorporating both limit order revision and limit order cancellation in the research. The results of the single duration model suggest that limit order placements are dependent not only on the characteristics of limit orders but also on the conditions of the stock market where the particular order is submitted. Specifically, a limit order with a larger size tends to achieve a better execution rate, but under unfavourable market conditions it is also revised and cancelled with a shorter duration than a limit order with a smaller size. The time-to-an-order-event is also found to be shorter when the limit order price is placed closer to the prevailing mid-quote, when the opposite-side liquidity increases, or when the same-side liquidity decreases.

Furthermore, a significant extension to the existing research is conducted by studying the multiple order events within the life of each limit order, utilising a survival analysis methodology with a multiple-spell duration model. This new approach, which is a major contribution of this thesis, deals with limit order events that take place beyond the first occurrence, subsequent to their submission into the limit order book. The order events represent a series of limit order actions which include limit order spells such as revision-to-execution, revision-to-revision, or revision-to-cancellation. Order executions are also divided into full and partial executions for a more thorough investigation. By allowing for duration dependence and addressing the unobserved heterogeneity, a multiple-spell duration model proves to be a more appropriate method to be used in the study of dynamic limit order placement strategies. This form of survival analysis is even more relevant when order placement activities are constructed from a series of multiple, linked order events rather than single, independent events. The empirical results suggest that the hazard rates of limit order event transitions are determined by a number of factors such as the limit order size, the limit price, the market liquidity, the previous duration of the limit order spell, as well as other unobserved factors. This chapter also extends the initial study to examine dynamic limit order placement strategies in the periods that followed the two major structural changes by technological improvement of the ASX. The evidence seems to suggest that a more volatile market associated with more high-frequency trading activities may contribute to a higher hazard rate of transitions to limit order revision and cancellation.

To gain a better understanding of the effects of dynamic order placement activities, it is important to understand the linkages between the multiple events that occur within the life of each limit order and be able to connect them in a meaningful way. The existing studies consider only order execution in examining the time-to-an-order-event and have not incorporated limit order revision and cancellation in their research (see, for example, Lo et al., 2002). Other studies, such as Hasbrouck and Saar

(2013), arbitrarily link order submission, execution and cancellation based on the order size and direction. *Chapter 4* of this thesis, on the other hand, contributes to the current literature by utilising a more reliable approach of constructing a full limit order life with order events that are non-arbitrarily linked to each other. This chapter also incorporates both limit order revision and cancellation as a part of a dynamic strategy in the examination of order placement activities.

Chapter 4 provides major contributions to the existing literature by closely examining the effects of dynamic order placement activities and providing an investigation into the revision and cancellation as well as execution activities of buy/sell limit orders, dynamically managed by traders. The chapter shows that such activities conducted by traders have a positive impact on the quality of the ASX in the earlier period prior to the structural changes. Specifically, they improve the level of liquidity and reduce short-term volatility in the market. However, this positive impact is reversed in the periods following the two structural changes that witness a significant reduction in the trading latency of the ASX. In particular, a higher level of order placement activities, including a higher intensity of limit order revision and cancelation, is actually harmful for the quality of the stock market. As a result, the short-term volatility is heightened, the spreads are widened and the depth of the limit order book is lowered. Nonetheless, the adverse effects of order placement activities are reduced when going from the ITS period to the period of ASX Trade, as market latency is lowered and technology is improved further. In addition, it is also found that traders dynamically manage their order placement activities in an attempt to respond to certain stock market conditions, before and after the structural changes and technological improvements. Specifically, traders are more motivated to increase their order placement activities in terms of revising or cancelling their submitted limit orders when the market becomes more volatile or less liquid. Traders are, therefore, required to be more active in monitoring their limit orders, especially when the market conditions alter adversely.

The structural changes of the ASX resulted in a significant reduction in market latency. This new trading environment allows for a higher level of high-frequency trading and it has also changed the way traders manage their order placement activities. By employing a new approach and utilising survival analysis with a multiple-spell duration model, *Chapter 5* examines dynamic order placement strategies and their aggressiveness in a low-latency market environment. Evidence is found to support for the two theories discussed in Hasbrouck and Saar (2009) which explain order placement behaviours, namely the 'cost of immediacy hypothesis' and the 'chasing hypothesis'. In particular, the results show that a higher initial aggressiveness of the submitted limit order could cause a higher hazard rate of order cancellation and a lower hazard rate of order revision. There is a tendency of canceling limit orders in favour of market orders in an effort to obtain an immediate execution when the market liquidity is improved. Moreover, when traders observe that the market moves away from the initial position, they tend to 'chase the market' by cancelling the submitted order and resubmitting a more aggressive one. Alternatively, traders may opt for the option of revising the limit order with a more aggressive price.

In addition, the results in *Chapter 5* also emphasise on how low-latency market conditions may affect dynamic limit order placement strategies. A reduction in stock market quality, with a higher level of short term volatility, a lower level of liquidity and a higher number of submitted fleeting orders, result in a higher intensity of limit order cancellation and limit order revision, including aggressive and defensive revision activities. Some specific distinctions in traders' behaviours are also found when comparing between the ITS period and the ASX Trade period, as well as when examining the sample of large-cap stocks and the sample of small-cap stocks.

The findings of this thesis present a significant contribution to the current literature by enhancing the existing knowledge of the role of dynamic order placement activities on the quality of the stock market, as well as improving the understanding of how traders dynamically manage their orders through their ability to revise or cancel submitted limit orders. As a result, the study is not only beneficial for academic researchers, but also for stock market participants and stock exchange regulators. The insights from this research provide important policy implications which could hopefully help in setting regulations such that an optimal and efficiently functioning stock market can be ensured.

1.3. Structure of the Thesis

The rest of the thesis is structured as the followings. *Chapter 2* presents a review of the current literature on dynamic order placement strategies, survival analysis and its applications, as well as provides a discussion on the recent stock market incidents. *Chapter 3* studies the determinants of dynamic limit order placement strategies utilising survival analysis with both single-spell duration and multiple-spell duration models. *Chapter 4* examines dynamic limit order placement activities and their effects on stock market quality. *Chapter 5* employs multiple duration analyses to investigate dynamic order placement strategies and aggressiveness in a low-latency market environment. *Chapter 6* presents the concluding remarks and discusses the areas for future research.

CHAPTER 2

LITERATURE REVIEW

2.1. Background

In the past two decades, the electronic limit order book has become increasingly popular in major securities markets. The literature on market microstructure has proven that limit order is an important means for trading, especially in a pure electronic limit order book market design. A limit order is an order to buy or sell a pre-specified amount of stocks at a pre-specified price. This is as opposed to market orders where orders are traded immediately at the market price. For a significant number of traders, the uncertainty in execution time is unimportant, as long as the execution price is guaranteed. In other words, the key benefit of limit orders is that they contain no price risk. This means that an amount of stocks is only bought or sold if the limit order price is reached. Nevertheless, this benefit also comes with an important cost, which is unguaranteed execution. The time it takes until execution of a limit order is dependent on a number of factors, including the submitted limit order price, the size of the limit order, the stock market conditions, as well as private information. As a result, the opportunity cost of waiting can be significant for some traders, which could induce them to opt for a shorter time-to-execution, or an immediate execution. Such traders may prefer the use of market orders instead of limit orders. Obviously, when submitting market orders, they are aware of the potential price risk, which could be significant if the stock market is highly volatile.

The research attention on limit order placement strategies has been growing over the past two decades (see, for example, Harris and Hasbrouck, 1996; Parlour, 1998; Foucault, 1999; Griffiths et al., 2000; Sandas, 2001; Lo et al., 2002; Ranaldo, 2004; Hasbrouck and Saar, 2013). Traders decide which strategies to utilise based on their trading objectives. They may opt for market orders or limit orders with an aggressive price if they need to finalise their transactions quickly. Traders can be more impatient in this case due to many reasons, including deadlines that they need to meet or if they have important information that will be publicly available soon. On the other hand, traders can choose to submit limit orders that are less aggressive and wait until their orders are picked up. Traders can be more patient in this case because they are more motivated by value or they are unable to continuously monitor movements of the stock market. Some of the previous studies attempted to derive optimal dynamic strategies for order placement in an effort to fulfil traders' objectives. Harris (1998), among other research, examines optimal dynamic order strategies by considering the trading objectives of three types of traders: a value-motivated trader, an informed trader, and an uninformed liquidity trader.

The existing literature has largely focused on dynamic order placement strategies with the selection of market orders or limit orders (see, for example, Harris and Hasbrouck, 1996; Parlour, 1998; Ahn et al., 2001); or order submission strategies where traders choose among market orders, limit orders, reserve (partially undisclosed) orders, and hidden (totally invisible) orders (see Buti and Rindi, 2011; Bacidore et al., 2003). Other studies argue that transaction costs act as a motive for order placement strategies (Cohen et al., 1981). Fung and Hsieh (1997) also investigate the empirical characteristics of dynamic trading strategies employed by hedge funds. However, many of these existing studies have ignored the fact that limit orders can be revised or cancelled. Order placement strategies involve not only order submission strategies but also order cancellation and order revision strategies. Limit order cancellation has only been examined in a small number of studies (see, for example, Hasbrouck and Saar, 2002; Ranaldo, 2004; Hall and Hautsch, 2006; Hasbrouck and Saar, 2009). The recent literature of market microstructure has also reported a significant increase in the amount of order cancellations observed in the stock exchange. More than one-third of the orders submitted on the NYSE are cancelled prior to their executions as being documented by Yeo (2006) and Ellul et al. (2007). Hasbrouck and Saar (2009) report that 93% of submitted limit orders are subsequently cancelled on INET[1]. They also interestingly show that, a number of order cancellations, which account for as much as 36.69% of limit orders, are placed in the system within only two seconds of limit order submission. Beside cancellations, order revisions are also very common and useful in a limit order market. Order revisions refer to the changes in the price, the size, or both, of an existing order. While order submission is the primary focus in most of the previous studies on order choice and placement strategies, the activities of order revisions seem to be largely disregarded. There are very few studies that touch on the subject of limit order revisions, despite their empirical and practical significance for investors, stock exchanges and academics. Liu (2009) and Fong and Liu (2010) are among the first empirical studies that shed light on the close linkages between limit order submission risks and activities of limit order cancellation and revision. They find that activities of order cancellation and revision are the outcome of traders' strategic actions to reduce risks which arise from supplying liquidity to the market. Fong and Liu (2009) also report that more than 60 percent of limit orders are cancelled or revised on the Australian Stock Exchange. These critical observations of limit order events occurring subsequent to order submissions have pointed to traders' tendency of constructing various dynamic limit order placement strategies in order to fulfil their trading objectives.

[1] INET is an electronic communication network (ECN) found from the merger of Island and Instinet in 2002. In 2005, INET was acquired by NASDAQ and it then became the main trading platform of NASDAQ after being integrated with SuperMontage and Brut system.

Furthermore, Fong and Liu (2010) suggest that traders do monitor their limit orders closely. The incentives for monitoring come from the fact that limit orders are subjected to submission risks, including non-execution and free-option risks. In addition, the monitoring cost of limit orders is also an important factor that affects the level of revision and cancellation activities. Other factors include the time of the trading day, order aggressiveness, order size, market liquidity, market volatility and depth of the limit order book. Cao et al. (2008) is another study that examines order placement strategies in the Australian Stock Exchange and shows that the top of the limit order book always affects limit order submission, revision and cancellation, whereas the rest of the limit order book mostly impacts limit order revision and cancellation. Besides, Menkhoff et al. (2010) provide evidence of informed and uninformed traders' responses to shocks in a limit order driven market. However, existing literature has not examined to a full extent the influences that these dynamic order placement activities have on the quality of the stock markets, especially when traders have the options to revise or cancel their limit orders.

2.2. Survival Analysis and Its Applications

The empirical analysis of survival data and its applications have become widespread, especially in labour economics, in demography as well as in medical science since the early 1980s. Survival analysis is probably regarded as one of the most important tools in econometrics because numerous types of behaviour overtime are considered as movements from one state to another at random intervals. For examples, individuals can move from being unemployed to being employed, or to a nonparticipation state in the labour market; an individual can move from being single to being married, or to being divorced; etc.

Applications of survival analysis have been dominant in the literature of economics, as shown in a wide range of economics research areas. In business economics, Nilsen and Schiantarelli (2003) study the duration until a major investment. In consumer economics, Boizot et al. (2001) study the survival time until purchase of a storable product. In migration economics, Lindstrom (1996) studies the duration until return migration. In labour economics, Devine and Kiefer (1991) examine the duration of jobs and the duration of unemployment, Kennan (1985) studies strike durations, and Bonnal et al. (1997) investigate the duration of training programs. In population economics, Lillard (1993) studies marriage durations; Heckman and Walker (1990) study the duration until a child is born; other studies apply survival analysis to examine the duration until death. Many economics research also utilise survival analyses in areas where the unit considered is not an individual. An example is Diebold and Rudebusch (1990), a macroeconomics study which uses survival analysis to investigate the duration of business cycles. In political economics, Horvath (1968) studies the duration of wars. Empirical applications of survival analysis have also been found in other research areas outside economics. Duration models are employed in marketing to study household purchase timing (see, for example, Vilcassim and Jain, 1991); in industrial organisation, Pakes and Schankerman (1984) study the duration of a patent; whereas in econometric analyses, Van den Berg and Lindeboom (1998) employ survival analysis to examine the duration of panel survey participation.

Some of the recent studies in the literature which consider the role of limit orders in the process of price discovery include Angel (1994), Foucault (1994), Glosten

(1994), Parlour (1998), Chakravarty and Holden (1995), and Sandas (2001). However, the focus of the above papers is generally on the role of the market maker, the choice of market orders or limit orders, and the interaction between the two types. Empirical applications of survival analysis are somewhat limited in finance literature, especially when it comes to the study of dynamic limit order placement strategies. Engle and Russell (1998) is one of the studies which apply survival analysis to examine the duration of share transactions in the stock market. Hollifield et al. (2004) also establish a structural model of a purely limit-order driven market. Their empirical model presents the tradeoff between the probability of order execution and the limit order price. The model is then estimated non-parametrically and the authors draw some implications regarding limit order submission strategies. However, most of these studies provide little direction for modeling limit-order execution times and the time-to-next-order-event. Lo et al. (2002) is a study which attempts to develop an econometric model of limit-order execution times utilising survival analysis. They estimate the model for time-to-first-fill and time-to-completion of both buy and sell limit orders, and the effects of explanatory variables can be incorporated. Some of the explanatory variables used include the bid/ask spread, the limit price, the limit size, and measures of market volatility. The study finds that execution times are not sensitive to the limit size but they are very sensitive to the limit price. However, Lo et al. (2002), together with the majority of studies in the same research area, generally concern with limit order execution times only. Revision and cancellation events have mostly been ignored, even though they are regarded as being highly important in the decision making process towards order placement (see, for example, Fong and Liu, 2010). Limit order revision and cancellation represent an important aspect of dynamic trading strategies, given the drastic transformation of the trading industry in recent years. As a result, the current literature provides little insights into the duration at which revision and cancellation activities take place during the course of the trading day.

In order to gain a deeper understanding of dynamic limit order placement strategies and their determinants, it is important to understand not only the duration of each limit order event, but also the connections of the consecutive events which occur throughout the entire life of each limit order. Consequently, there is an apparent need for the development of a duration model that can capture the effects of multiple limit order events. For this reason, survival analysis methodology with a multiple-spell duration model is perhaps among the most relevant choices of econometric techniques. Multiple-spell duration models have been utilised more widely in biomedical science and also in labour economics. In studying the employment dynamics, the model is used to describe the labour market transitions when an individual moves through the states of unemployment and temporary employment multiple times, or in and out of the labour force. The Proportional Hazard (PH) model is probably one of the most popular duration models based on specifications of the hazard function which have been employed widely for analysing multiple-spell data (Van Den Berg, 2001). There are quite a few empirical analyses of PH models with multiple-spell duration data in the literature of biomedical science and labour economics. For examples, Newman and McCullogh (1984) who estimate models for birth intervals using multiple-spell duration data; Ham and Rea (1987) who employ a discrete-time model; and Coleman (1990) who estimates a reduced-form of unemployment duration models. Lillard (1993) and Lillard and Panis (1996) also use a set of multi-spell data to estimate marriage duration models. In addition, Honore (1993) provides a lagged duration dependence specification, where the duration of the first spell enters the hazard of the second spell multiplicatively. Among the studies in the literature of labour economics, Gagliarducci (2005) applies a multiple-spell duration technique to examine the transition to employment from a sequence of different periods, including periods of temporary employment and unemployment. The study utilises an econometric model that differentiates individuals based on their situation in the labour market. The three scenarios are established for the individuals: working in a permanent job, working in a temporary job, or non-working. Gagliarducci (2005) finds that the chance of transiting from temporary employment to permanent employment is higher when the contract has a longer duration. However, the transition probability is lower when the temporary jobs are repeated, or when there are periods of interruptions. Despite its popularity in economics applications, survival analysis with a multiple-spell duration model has not been utilised to a large extent in the literature of financial market microstructure, especially in examining dynamic limit order placement strategies[2].

2.3. Recent Stock Market Incidents

As a result of better access to stock exchanges and information via electronic connections, low-latency trading by algorithms has led to a significant reduction in monitoring cost, and thus, lower limit order submission risks to some extent. Nevertheless, this also gives rise to algorithmic arms race between competing trading firms, which could pose significant risks for the exchanges when the trading environment experiences extreme adverse conditions (see, for example, Goldstein and Kavajecz, 2004).

[2] To the best of my knowledge, this thesis is the first research that utilises survival analysis approach with a multiple-spell duration model to study dynamic limit order placement strategies.

Some of the most recent disastrous incidents include the stock market flash crash in May 2010 and the Knight Capital's trading glitch in August 2012. On Thursday May 6th, 2010, the US Dow Jones Industrial Average experienced the second largest intraday point swing in its history (Lauricella and McKay, 2010). The Dow stock index plunged by more than 1000 points, or about nine percent, only to recover nearly two third of the losses within minutes. High-frequency traders and their aggressive algorithmic reactions to the sudden changes in the market were blamed for contributing to the extraordinary turbulence in the market place on that historic day. When the stock market experiences a rapid decline, aggressive stock selling was escalated by the high-frequency traders. A large number of other traders were also forced to scale down or stop their trading. The total effect was a significant reduction in liquidity which contributed further to the deep fall in the stock markets. On a more recent day, August 1st, 2012, another flash crash happened in the US stock market. A major trading technical malfunction of the US-based brokerage Knight Capital caused the prices of 140 stocks listed on the New York Stock Exchange (NYSE) to fluctuate wildly. As a consequence, Knight Capital revealed that it would face $440m in pre-tax losses, and the group's stocks traded down by nearly 65% in the matter of just a couple of days.

The recent events and incidents happened in the world stock markets have raised critical questions for market participants, regulators as well as researchers to consider: What are the factors that determine active trading activities and dynamic order placement strategies, especially in a low-latency environment? Have these activities actually improved or reduced market quality? The existing literature on market microstructure has failed to provide satisfactory answers to these questions, especially when it comes to the situation where dynamic order placement activities can involve limit order revisions as well as cancellations.

A number of recent theoretical research papers attempt to shed light on the potential impacts of active low-latency trading in financial markets. These include Cvitanic and Kirilenko (2010), Hoffmann (2010), Biais et al. (2011), Cartea and Penalva (2011), Cohen and Szpruch (2011), Jarrow and Protter (2011), Jovanovic and Menkveld (2011), Hasbrouck and Saar (2013), Martinez and Rosu (2013), and Gerig and Michayluk (2014). Some of these papers have specific implications regarding the impacts of high-frequency trading on market liquidity and volatility. For example, Cartea and Penalva (2011) build an empirical model based on the framework of Grossman and Miller (1988). This model, however, includes high-frequency traders who take two different roles: as market makers and as liquidity traders. The study finds that when high-frequency trading occurs in the market, it adversely affects liquidity traders and it also raises market volatility. Another study by Gerig and Michalyuk (2014) suggests that high-frequency traders have the ability to extract information related to prices from various securities more efficiently than other participants in the market. These automated liquidity providers can use information from one stock to price a different stock, thus transaction costs can be reduced and more favourable prices can be offered to the market. Hoffman (2010) utilises the limit order book model of Foucault (1999), but incorporating high-frequency traders in the model. The research finds that fast traders create a higher competition in supplying liquidity, therefore transaction costs are reduced significantly. Furthermore, the theoretical models developed by Biais et al. (2011) as well as Jovanovic and Menkveld (2011) also propose that high-frequency trading can have either a positive or a negative effect on the stock market depending on the assumptions of the trading strategies and the economy structure. However, a theoretical model which concentrates on an assumption of one strategy may not accurately account for the total impact since there can be a mixture of strategies in the market due to the fact that different algorithmic traders may use different strategies.

Brogaard et al. (2014) utilise the NASDAQ HFT data to examine the contribution of high-frequency trading to price discovery and conclude that the efficiency in prices is improved when the market involves more high-frequency traders. Nevertheless, it is worth noting that low-latency trading could also affect the stock market adversely, especially in the periods of high volatility. The stock market flash crash in May 2010 is a great example of the massive destruction in the market that could be caused by such trading activities. In addition, Kirilenko et al. (2014) examine the behaviour of firms who conduct high-frequency trading in the futures market on the day when the flash crash occurred. They find that the crash was not triggered by the high-frequency traders, but their trading activities as a response to the crash played an important part in exacerbating the extreme volatility in the market[3]. On the other hand, Hasbrouck and Saar (2013) argue that the behaviour of low-latency trading in such extreme conditions should not be generalised for other market conditions. Their study examines the effect of such activities on the quality of stock markets using two distinct sample periods: the normal period and the period of falling prices and rising volatility[4]. Their findings suggest that market quality is, in fact, improved in both periods with a higher level of low-latency trading. These trading activities also help reduce volatility for small stocks, especially during periods of market decline. The study, however, acknowledges that its findings should not imply volatility of the brief and extreme

[3] Kirilenko et al. (2014) characterise a high-frequency trader as one who executes a significant amount of transactions on a daily basis. Such trader also needs to satisfy a specific category of net positions, on the basis of intraday as well as end of day. Using such selection criteria, the paper identifies 16 firms who conduct high-frequency trading in the S&P 500 E-mini futures contract.

[4] Hasbrouck and Saar (2013) use two distinct sample periods in their study. The first period is October 2007 with a relatively flat or slightly increasing stock market. The second period is June 2008, when the market entered deep decline and was highly uncertain, starting with the Bear Stearns incident. It is worth noting that the NASDAQ index dropped by 8% in the month of June 2008.

periods (such as the stock market flash crash), could be reduced by an increase in the level of activities by low-latency traders.

CHAPTER 3

DETERMINANTS OF DYNAMIC LIMIT ORDER PLACEMENT STRATEGIES - SURVIVAL ANALYSIS WITH A MULTIPLE-SPELL DURATION APPROACH

3.1. Introduction

The literature on market microstructure has proven that limit order is one of the most essential tools in equity trading, especially in a market design with a pure electronic limit order book. Angel (1994), Chakravarty and Holden (1995), Parlour (1998), and Foucault (1999) are some examples of an extensive number of studies which examine the role of limit orders in term of price discovery. These papers attempt to answer the research questions of how limit orders affect the stock market and how they interact with market orders. Another research, Hollifield et al. (2004), also considers a pure limit-order market and constructs a model to study the trade-off between the price and the chance of execution of a limit order. The paper provides some insights into trading strategies through order submission. However, all of these studies provide little direct guidance for modelling limit-order execution times and time-to-next-order-event.

The evidence in the existing literature has been very limited regarding the duration at which revision and cancellation activities take place during the course of the trading day. Previous studies on duration analysis only examine the time-to-execution and largely ignore the time-to-revision and time-to-cancellation. This is an important aspect of dynamic trading strategies, given the drastic transformation of the trading industry in recent years. To better understand dynamic limit order placement strategies and their determinants, it is important to understand the duration of each order event and the multiple events that occur within the life of each limit order. The majority of the existing studies only provide analysis on single duration model which solely concerns with the time-to-execution (see, for example, Lo et al., 2002). Revision and cancellation events are considered as censored observations and are not examined in those studies.

This chapter goes beyond the current literature by extending the single duration model to also study time-to-revision and time-to-cancellation. The effects of limit order characteristics and market conditions are examined on the revision and cancellation times as well as execution times. Furthermore, another step is taken forward to extend the research by utilising a survival analysis methodology with multiple-spell duration model. To the best of my knowledge, this thesis is the first study that employs multiple-spell duration model for this research purpose. This innovative approach deals with limit order events that take place beyond the first occurrence, subsequent to the limit order's submission into the stock exchange. These limit order actions represent a series of successive order events such as revision-to-execution, revision-to-revision, or revision-to-cancellation. This chapter extends the related studies by incorporating a multiple-spell duration model with an innovative approach to enhance the understanding of the characteristics of dynamic limit order placement strategies.

The results of this chapter suggest that limit order placements are dependent not only on the characteristics of limit orders but also on the conditions of the stock market where the order is submitted. Specifically, a limit order with a larger size seems to be executed quicker and also revised and cancelled in shorter times under unfavourable market conditions. Moreover, the time-to-next-order-event is reduced when the gap between limit order price and the prevailing mid-quote decreases, when the opposite-side liquidity increases and when the same-side liquidity drops. In this market, traders are also found to revise buy limit orders quicker and more aggressively than sell limit orders. Time-to-cancellation tends to be the shortest in comparison with the time it takes from limit order submissions to executions and from submissions to revisions, for both small and large stocks, across both limit buy and sell orders. By allowing for duration dependence and addressing the unobserved heterogeneity, a multiple-spell duration model has proved to be an appropriate approach of survival analysis that can be used to study the dynamic of limit order placement strategies. This is because an order placement strategy is constructed from a series of multiple, linked order events rather than from single, independent events. The empirical results suggest that a number of factors help determine the hazard rates of transitions of limit order events to order revisions and order cancellations. For example, larger opposite-side liquidity motivates traders to intensify their revision and cancellation activities, and hence a higher occurrence probability of revision and cancellation limit order events. This chapter also extends the research to investigate the dynamic limit order placement strategies following the two major structural changes by technological advancement of the Australian Securities Exchange (ASX) in 2006 and 2010. The evidence seems to suggest that more volatile market associated with more activities of high-frequency trading may lead to higher intensity of limit order revisions and cancellations.

The rest of this chapter is structured as the followings. *Section 3.2* introduces the trading systems of the ASX and describes the order data used for this study. *Section 3.3* presents the empirical methodology, including survival analyses with single-spell and multiple-spell duration models. This section also introduces the explanatory variables and how they are constructed. *Section 3.4* explains the empirical results for the survival analyses, including the extension to examine multiple-spell duration models in the two samples that follow the ASX's major structural changes of its trading platform. Finally, *Section 3.5* concludes the chapter.

3.2. ASX Order Data

3.2.1. Trading Systems of the Australian Securities Exchange (ASX)

The Australian Securities Exchange is a securities market that relies solely on the liquidity provided by investors. There are no designated market makers or dealers on the ASX. It is considered as a highly transparent market where traders are likely to act strategically, taking into account the strategies of other traders (Xu, 2009). The ASX had employed the fully computerised Stock Exchange Automated Trading System (SEATS) from 1987 to 2006. In October 2006, SEATS was replaced by the Integrated Trading System (ITS), which is a fully-electronic trading system utilised for its efficiency in dealing with fast transactions. ITS still kept the same trading rules and market structure of the ASX, at the same time provided a number of operational improvements over SEATS. From November 2010, ASX Trade, an ultra-low latency trading platform, was put in place to replace ITS. It is powered by NASDAQ OMX's Genium INET platform, providing one of the fastest integrated equities and derivative platforms in the world.

3.2.2. Limit Order Data

This chapter investigates the dynamic order placement activities of the 40 index stocks listed on the ASX over the three sample periods, year 2000, year 2007 and year 2011. 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. For the purpose of this study, small-cap stocks are chosen as the 20 common stocks ranked from 111th to 130th on the ASX200 index. Year 2000 is chosen since it was the year that the ASX200 index was formed and started its operation. Year 2007 and 2011 are chosen as they were the years that immediately followed the inceptions of ITS and ASX Trade, respectively. In each sample period, the month of August is chosen as the sample period of interest for research as most preliminary end-of-year earning reports are released in August. This also means that more trading activities are expected in August as a result. The dataset is provided by the Securities Industry Research Centre of Asia-Pacific (SIRCA). It records each order and trade including the date, time, stock code, price, transacted volume and order types. Orders that are revised (either an order-price revision, or an order-volume revision, or both) as well as the ones that are cancelled or executed after submissions, are recorded separately. In the sample under study, market orders account for about 55% and limit orders account for about 45% of the order submissions. Apart from the number of executions, revision order events account for close to 50% of limit orders, whereas cancellation events also make up a significant number, which is about 20% of all limit orders. The statistics clearly indicate that investigating the limit order placement strategies cannot be thoroughly carried out without paying special attention to the revision and cancellation activities.

3.3. Empirical Methodology

3.3.1. Construction of Full Order Lives

The empirical study of this thesis starts with the construction of the full limit order lives. For each limit order submitted into the order book, this process creates a series which links all events that occur during the entire life of that order. A limit order's life is ended when it is fully executed or fully cancelled from the limit order book. Using the unique cross reference ID number that is assigned for each order, it is possible to trace all types of events and their associated data which are observed throughout the entire life of an order. Following its submission into the limit order book, a limit order can be fully executed, partially executed, revised, or cancelled. If the limit order is partially executed or revised, the possible subsequent events will be the same as in the first phase. That is, the partially executed or revised order can be followed by a full execution, a partial execution, a revision or a cancellation order event. *Figure 3.1* provides a snapshot of the general transitions of limit order events.

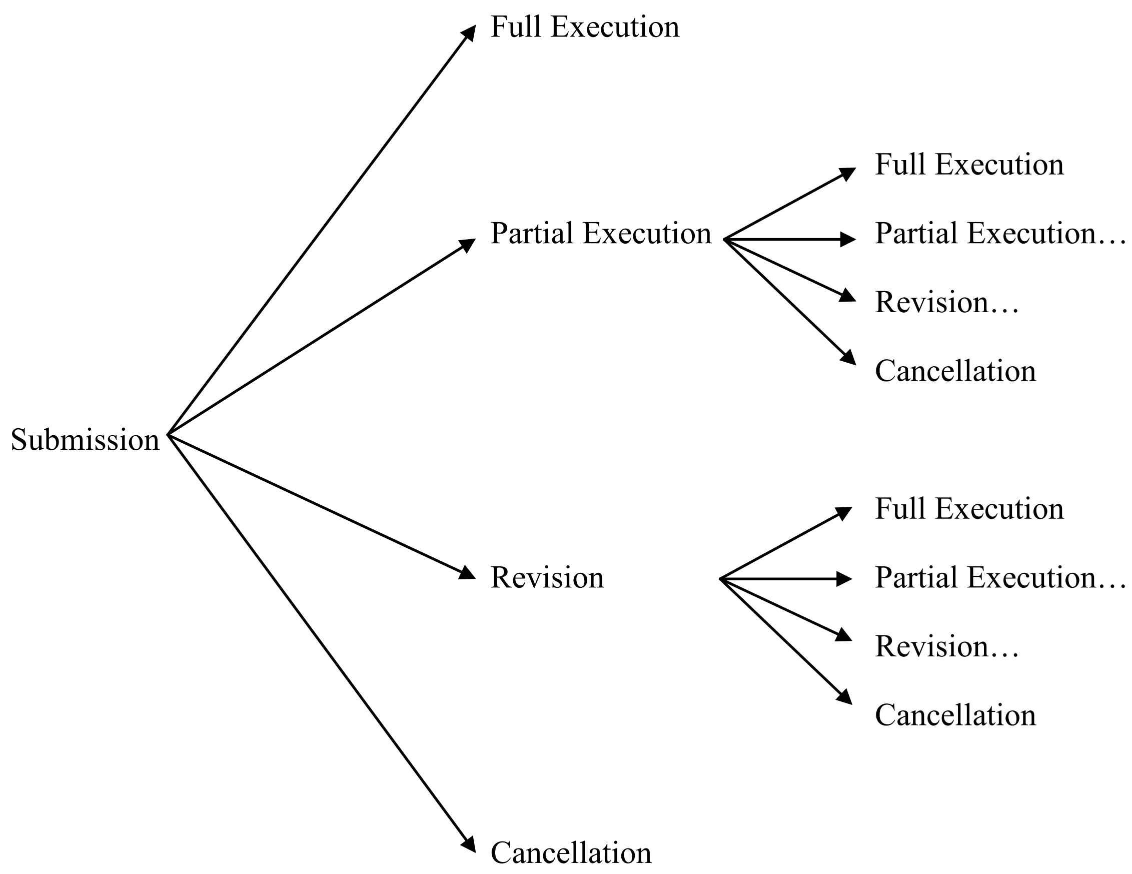

Figure 3.1. The general transitions of limit order events

3.3.2. Survival Analysis with a Single-Spell Duration Model

The first approach is to employ survival analysis with a single-spell duration model to study dynamic limit order placement strategies and their determinants. This methodology models the time-to-first-order-event that occurs in the life of a limit order. This includes the time-to-execution, time-to-revision and time-to-cancellation. The analysis is carried out separately for buy limit orders and sell limit orders as well as for large-capitalisation stocks and small-capitalisation stocks.

Survival analysis involves a nonnegative random variable which represents the length of a limit order spell. Let *T* be this random variable, then *T* represents the time it takes for a limit-order to transit from one event to another (time-to-an-order-event). If $h(t)$ is the hazard rate of *T* at time *t*, then $h(t)\ dt$ shows the probability that an order which has survived (being placed with one event) through time *t* will fail (being placed with another event) in the interval $[t, t+dt)$. Let $f(t)$ be the probability density function (PDF) of *T* and let $F(t)$ be the cumulative density function (CDF) of *T*, then the hazard function can be defined as:

$$h(t) = \frac{f(t)}{1 - F(t)} \tag{3.1}$$

The hazard rate is the rate at which an order spell is completed (an order is completely transited from one event to another) after duration *t*, given that they last at least until time *t*. The survival function can also be defined as $S(t) \equiv 1 - F(t)$. This survival function shows the probability that the length of an order spell will be at least *t*.

In order to estimate hazard function and survival function, a non-parametric or a parametric survival analysis can be utilised. The non-parametric approach does not rely on any parametric assumption when estimating the survival function. On the other hand, the parametric approach assumes a particular parametric distribution of failure times and the survival function can be estimated using maximum likelihood based on the distributional assumption. This research employs a parametric survival analysis in the empirical methodology due to its dominance over the non-parametric counterpart (see, for example, Lo et al., 1999). There are a large number of distributions for failure times which have been used extensively in the literature. Some examples include exponential, gamma, Weibull, lognormal, F, inverse Gaussian as well as many other distributions. For the purpose of this study, an exponential distribution is chosen as this type of distribution is probably one of the most widely used specifications in parametric approach for duration analyses (see, for example, Cox and Oakes, 1984; Lancaster, 1992; Kalbfleisch and Prentice, 2011).

Similar to Lo et al. (2002), this research utilises an *accelerated failure time* model for the single-spell duration analysis. For survival analysis with single-spell duration, the dependence of failure times on explanatory variables can be addressed by assuming that the effect is captured by rescaling time. Therefore, this method creates an accelerated failure time specification with an exponential factor employed to rescale time. The model specification has the following form:

$$T = e^{X'\beta} T_0 \tag{3.2}$$

where T is the time-to-an-order-event, X is the set of explanatory variables, β is a vector of parameters, T_0 is the baseline failure time.

3.3.3. Survival Analysis with a Multiple-Spell Duration Model

This study extends beyond the current literature by taking a further investigation to examine the multiple events that occur through out the entire life of limit orders. As a result, survival analysis with a multiple-spell duration approach is also employed in this chapter. This research is probably the first study that utilises both single-spell and multiple-spell survival analyses to examine dynamic limit order placement strategies and their determinants.

Multiple-spell duration model has been used more widely in biomedical science and labour economics. In studying the employment dynamics, the model is employed to describe the labour market transition when an individual passes through the unemployment and temporary employment states multiple times or in and out of the labour force. The Proportional Hazard (PH) model is perhaps one of the most popular duration models based on specifications of the hazard function and has been used extensively for multiple-spell data (Van Den Berg, 2001). There are quite a few empirical analyses of PH models with multiple-spell duration data in the literature of biomedical science and labour economics. Some examples include Newman and McCullogh (1984) who estimate models for birth intervals using multiple-spell duration data; Ham and Rea (1987) who employ a discrete-time model; and Coleman (1990) who estimates a reduced-form of unemployment duration models. Other relevant studies include Lillard (1993) and Lillard and Panis (1996) who also use a set of multi-spell data to estimate marriage duration models. Moreover, Honore (1993) utilises a lagged duration dependence specification, where the duration of the first spell enters the hazard of the second spell multiplicatively.

Among the studies in the literature of labour economics, Gagliarducci (2005) applies a multiple-spell duration model to study the path to a permanent job from a sequence of temporary contracts and periods of unemployment. The research attempts to capture the dynamic effects of employment by using an econometric specification that divides labour market circumstances into three scenarios: non-working (NW), temporary employment (TE) and permanent employment (PE). As a result, there are a total of seven transitions that are considered in their analysis: NW-TE, NW-PE, TE-PE, TE-TE, TE-NW, PE-TE and PE-NW. This econometric specification is, in fact, comparable to the study of this chapter since following submission, a limit order can pass through a sequence of multiple events before it can be fully filled or completely cancelled from the system.

The common successive events of submitted limit orders include (i) submission-to-full-execution, (ii) submission-to-partial-execution, (iii) submission-to-revision, (iv) submission-to-cancellation, (v) partial-execution-to-full-execution, (vi) partial-execution-to-partial-execution, (vii) partial-execution-to-revision, (viii) partial-execution-to-cancellation, (ix) revision-to-full-execution, (x) revision-to-partial-execution, (xi) revision-to-revision, (xii) revision-to-cancellation. Indeed, *Figure 3.1* has shown a diagram which describes the transitions of limit order events. In the above transitions, the order events in the left-hand side are said to be in the *origin states* and the order events in the right-hand side are said to be in the *destination states*.

Using the order reference number and time, it is possible to track subsequent execution, revision and cancellation order events that follow an order submission. *Table 3.1* provides the length and frequency analysis of limit order events for buy and sell orders of the 40 reference stocks in the initial sample of August 2000.

Table 3.1: Length and Frequency of Limit Order Events

PANEL A: BUY ORDERS

Order Length	Frequency	Percentage	Cumulative Frequency	Cumulative Percentage
1	5,582	3.67	5,582	3.67
2	94,069	61.77	99,651	65.43
3	27,595	18.12	127,246	83.55
4	11,632	7.64	138,878	91.19
5	5,539	3.64	144,417	94.83
6	2,908	1.91	147,325	96.74
7	1,694	1.11	149,019	97.85
8	1,018	0.67	150,037	98.52
9	646	0.42	150,683	98.94
10	419	0.28	151,102	99.22
11	306	0.20	151,408	99.42
12	217	0.14	151,625	99.56
13	162	0.11	151,787	99.67
14	95	0.06	151,882	99.73
15	88	0.06	151,970	99.79
16	67	0.04	152,037	99.83
17	44	0.03	152,081	99.86
18	39	0.03	152,120	99.89
19	19	0.01	152,139	99.90
20	34	0.02	152,173	99.92
21	15	0.01	152,188	99.93
22	23	0.02	152,211	99.95
23	16	0.01	152,227	99.96
24	11	0.01	152,238	99.97
25	8	0.01	152,246	99.97
26	8	0.01	152,254	99.98
27	3	0.00	152,257	99.98
28	6	0.00	152,263	99.98
29	2	0.00	152,265	99.98
30	6	0.00	152,271	99.99
31	2	0.00	152,273	99.99
32	4	0.00	152,277	99.99
33	2	0.00	152,279	99.99
34	1	0.00	152,280	99.99
35	1	0.00	152,281	99.99
36	1	0.00	152,282	99.99
37	1	0.00	152,283	99.99
38	1	0.00	152,284	100.00
40	1	0.00	152,285	100.00
41	1	0.00	152,286	100.00
42	1	0.00	152,287	100.00
44	1	0.00	152,288	100.00
46	1	0.00	152,289	100.00
50	1	0.00	152,290	100.00
59	1	0.00	152,291	100.00

PANEL B: SELL ORDERS

Order Length	Frequency	Percentage	Cumulative Frequency	Cumulative Percentage
1	6,733	4.40	6,733	4.40
2	94,676	61.94	101,409	66.34
3	26,697	17.47	128,106	83.81
4	11,791	7.71	139,897	91.52
5	5,248	3.43	145,145	94.96
6	2,902	1.90	148,047	96.86
7	1,672	1.09	149,719	97.95
8	1,050	0.69	150,769	98.64
9	623	0.41	151,392	99.04
10	387	0.25	151,779	99.30
11	252	0.16	152,031	99.46
12	182	0.12	152,213	99.58
13	149	0.10	152,362	99.68
14	95	0.06	152,457	99.74
15	84	0.05	152,541	99.80
16	61	0.04	152,602	99.84
17	42	0.03	152,644	99.86
18	40	0.03	152,684	99.89
19	35	0.02	152,719	99.91
20	31	0.02	152,750	99.93
21	19	0.01	152,769	99.94
22	13	0.01	152,782	99.95
23	12	0.01	152,794	99.96
24	9	0.01	152,803	99.97
25	12	0.01	152,815	99.97
26	3	0.00	152,818	99.98
27	3	0.00	152,821	99.98
29	6	0.00	152,827	99.98
30	6	0.00	152,833	99.99
31	2	0.00	152,835	99.99
32	2	0.00	152,837	99.99
34	1	0.00	152,838	99.99
35	1	0.00	152,839	99.99
36	1	0.00	152,840	99.99
37	3	0.00	152,843	99.99
38	1	0.00	152,844	99.99
39	1	0.00	152,845	99.99
40	1	0.00	152,846	99.99
41	2	0.00	152,848	100.00
42	1	0.00	152,849	100.00
52	1	0.00	152,850	100.00
55	1	0.00	152,851	100.00
66	1	0.00	152,852	100.00
75	1	0.00	152,853	100.00
100	1	0.00	152,854	100.00

Table 3.1 illustrates clearly that many orders in the sample experience more than one event from their submission into the system. Indeed, about 96.74% of buy orders experience up to 5 events following their submission into the limit order book. The corresponding statistic for the sell orders is 96.86%. In the case of buy orders, up to 23 events are experienced by at least double-digit number of orders in the sample. Whereas, up to 24 events are experienced by at least double-digit number of sell orders. A multiple-spell duration model could, therefore, be employed for this study since they allow the duration of an event to be dependent, not only on the order characteristics, but also on the preceding events and their durations.

Let t_i be a sequence of adjacent periods of time (spells) spent in different states. For each series of limit order events of a stock, a sequence $t_i=\{t_i^c\}$ is observed. The duration spent is denoted by t, the particular series of limit order events occur for an individual stock is denoted by the subscript i and the c^{th} spell in a specific state is denoted by the superscript c. This study utilises a multiple-spell duration model specification similar to that employed in Gagliarducci (2005). The *hazard rate*, θ_{kj}, is defined as the intensity of the transition to the *destination state* (denoted by j) after a visit in the *origin state* (denoted by k). The function of the *hazard rate*, θ_{kj}, for the series i at its c^{th} spell is expressed as the following:

$$\theta_{kj}\left(t_i^c \middle| X_{ikj};\beta\right) = h_{kj}(t_i^c)\exp\,(\beta'_{kj}X_{ikj})v_{ikj} \tag{3.3}$$

where $h_{kj}(t_i^c)$ is a baseline hazard; X_{ikj} is a set of explanatory variables which incorporate both stock market conditions and limit order characteristics that can influence the decisions and strategies for dynamic order placements; and v_{ikj} is a random individual effect to capture the unobserved heterogeneity. All the individual covariates, X_{ikj} , which determine the hazard rate of transition between limit order events, are fixed to their values at the beginning of each spell. The construction of the explanatory variables is detailed below in *Section 3.3.4*.

3.3.4. Incorporating Explanatory Variables in the Duration Models

The best feature of the duration models employed in this research is that they allow for the inclusion of explanatory variables which describe the limit order characteristics and the stock market conditions in which the order events occur. Since the survival times of limit orders depend on several factors such as limit order price, order size, market depth and market liquidity, the limit order characteristics and market conditions are highly influential on the decisions and strategies for dynamic order placements. This chapter utilises a similar set of explanatory variables to those used in Lo et al. (2002). For the single-spell duration model, explanatory variables are measured at the time an order is submitted into the order book, whereas in the multiple-spell duration model, they are measured at the beginning of each limit order spell. The variables are defined and calculated separately for buy and sell limit orders.

Let *P* be the most recent transaction price, *L* be the limit price, *B* be bid price, *A* be the ask price, *MQ* be the mid-quote price, S_b be the bid size, S_a be the ask size and S_l be the limit order size. For buy limit orders, the explanatory variables are defined as the followings:

PRICEGAP = *MQ* – *L*

INITRADE = 1 if the previous transaction price is greater than *MQ*

$= -1$ if the previous transaction price is less than MQ

$= 0$ if the previous transaction price is equal to MQ

$$SSLIQUIDITY = (1 + B - L) \times \log S_b \quad \text{if } L \leq B$$

$$= 0 \quad \text{if } L > B$$

$$MKDPR = (P - L) \times SSLIQUIDITY \quad \text{if } P \geq L$$

$$= 0 \quad \text{if } P < L$$

$$OSLIQUIDITY = \log S_a/(1 + A - L) \quad \text{if } A \geq L$$

$$= \log S_a \quad \text{if } A < L$$

$$ORDSIZE = \log S_l\,(1 + A - L) \quad \text{if } A > L$$

$$= \log(S_l - S_a) \quad \text{if } A = L \text{ and } S_l > S_a$$

$$= 0 \quad \text{if otherwise}$$

The above explanatory variables capture the characteristics of the limit orders as well as the conditions of the stock market where the orders are placed. The variable *PRICEGAP* measures the distance of the limit buy price from the mid-point of the prevailing quotes. The variable *INITRADE* indicates if the transaction occurred previously was a buyer-initiated trade or a seller-initiated trade. *SSLIQUIDITY* is the same side (buying side) liquidity and is constructed as a measure of the market depth scaled by the distance between the bid price and the limit buy price. The variable *MKDPR* is an interactive term added to the model to capture nonlinearities between market depth and market price relative to the limit price. *OSLIQUIDITY* shows the liquidity that is available in the market on the opposite side (selling side). *OSLIQUIDITY* decreases as limit buy price drops below the ask price. The variable *ORDSIZE* is a measure that captures the number of shares demanded by the limit order and the measure is scaled by the difference between limit buy price and the ask price.

For sell limit orders, the explanatory variables are defined in a similar way as buy limit orders. Even though the economic interpretations are similar, the directions of some of the effects are opposite to the situation of buy limit orders. As a result, four of the above explanatory variables are redefined as the followings:

PRICEGAP	$= L - MQ$	
SSLIQUIDITY	$= (1 + L - A) \times \log S_a$	if $L \geq A$
	$= 0$	if $L < A$
MKDPR	$= (P - L) \times SSLIQUIDITY$	if $P \leq L$
	$= 0$	if $P > L$
OSLIQUIDITY	$= \log S_b/(1 + L - B)$	if $B \leq L$
	$= \log S_b$	if $B > L$
ORDSIZE	$= \log S_l\,(1 + L - B)$	if $L > B$
	$= \log(S_l - S_b)$	if $L = B$ and $S_l > S_b$
	$= 0$	if otherwise

The summary statistics of the above explanatory variables are presented in *Table 3.2*.

Table 3.2: Summary Statistics of Explanatory Variables

This table presents the summary statistics for the explanatory variables used in survival analyses. The Proportional Hazard model estimates the effects that limit order characteristics and market conditions have on the duration of order events. Detailed descriptions of the explanatory variables are given in the text.

	PRICEGAP	*INITRADE*	*SSLIQUIDITY*	*MKDPR*	*OSLIQUIDITY*	*ORDSIZE*
Panel A: Buy Limit Orders						
Mean	0.017	-0.001	4.875	0.722	8.128	8.374
Median	0.005	0.000	6.313	0.000	8.247	8.602
25th Percentile	-0.005	-1.000	0.000	0.000	6.979	7.529
75th Percentile	0.015	1.000	8.896	0.087	9.331	9.369
Number of Observations	162795	162795	162795	162795	162795	162795
Panel B: Sell Limit Orders						
Mean	0.019	-0.003	4.967	-4.560	8.146	8.435
Median	0.005	0.000	6.435	0.000	8.268	8.602
25th Percentile	-0.005	-1.000	0.000	-0.088	6.939	7.537
75th Percentile	0.015	1.000	8.912	0.000	9.393	9.395
Number of Observations	158210	158210	158210	158210	158210	158210

In addition, survival analysis with multiple-spell duration also includes *PREVDUR* as an additional explanatory variable. This variable is defined as the time spent previously in the preceding states prior to the current limit order spell. It is used in a multiple-spell duration model to ensure that the duration dependence between successive spells is taken into account in the analysis.

3.4. Empirical Results

3.4.1. Duration of Limit Order Events

Table 3.3 presents the first look at the duration of limit order events. This is an examination of the time taken between order events in the initial data period (August 2000 sample). The statistics are computed for the time taken from order submission to order execution, submission to revision, and submission to cancellation. The table reports both the mean and median of the time taken (in minutes). The statistics are described separately for buy and sell limit orders across different categories of stocks (large, small and both). It is evidenced that, on average, the time taken for a buy limit order of small stocks to be revised from submission is 31.97 minutes. This number is significantly lower for large stocks. It only takes about half of the time, or 16.82 minutes, for a buy limit order of large stocks to be revised from submission. The corresponding average time of order revision from submission of sell limit orders is 44.04 minutes for small stocks and 21.34 minutes for large stocks.

Table 3.3: Duration of Limit Order Events

This table presents summary statistics of the time taken between various types of order events, i.e. the limit order duration, in the data sample of August 2000. The table includes the time taken from order submission to order execution, submission to revision, and submission to cancellation. Both the mean and the median of the time (in minutes) are reported. These statistics are described separately for buy and sell limit orders across different categories of stocks (large, small and both).

	Buy Orders		**Sell Orders**	
	Mean	*Median*	*Mean*	*Median*
Panel A: Large Stocks				
Submission to Execution	11.91	1.03	12.08	1.08
Submission to Revision	16.82	3.53	21.34	3.85
Submission to Cancellation	29.25	5.37	28.59	4.89
Panel B: Small Stocks				
Submission to Execution	28.69	6.44	28.24	5.78
Submission to Revision	31.97	7.98	44.04	13.50
Submission to Cancellation	58.61	22.43	55.75	15.98
Panel C: Large & Small				
Submission to Execution	14.14	1.30	14.26	1.35
Submission to Revision	19.24	3.88	24.92	4.62
Submission to Cancellation	34.60	7.07	32.52	5.90

The statistics are somewhat consistent with the results obtained from the research of Fong and Liu (2010), which also suggest that orders associated with larger stocks tend to be monitored more closely. As there is a higher level of revision activities happening with limit orders of larger stocks, it also takes a shorter time for these activities to occur. In addition, the average time it takes for order revisions is longer than that of order executions. The difference, however, is smaller for buy limit orders and is much larger for sell limit orders. Revisions tend to occur at a much slower pace than executions for sell limit orders, in both small and large stocks. It therefore seems to suggest that, in this initial period, traders tend to be more aggressive in purchasing trades than in selling trades. Once traders miss their chance of executions in their buy limit orders, they tend to respond quicker and revise their limit orders in an attempt to gain a higher probability of execution. On the other hand, traders tend to be more reluctant in revising their sell limit orders. The average time it takes from order submission to order revision of a sell limit order is almost double what it takes from order submission to order execution. Finally, the average time it takes for order cancellation seems to be the longest, for both buy and sell orders, in both cases of small and large stocks.

3.4.2. Survival Analysis with a Single-Spell Duration Model

In this study, survival analysis is employed with single-spell duration model as the main statistical tool to address the research question on the determinants of dynamic limit order placement strategies. The model incorporates a number of explanatory variables which capture the limit order characteristics as well as the stock market conditions where the limit order is submitted. The previous studies which use single-spell duration models only examine time-to-execution and largely ignore, or censor, the time-to-revision and time-to-cancellation. This chapter extends on the literature by investigating all order events. The parameter estimations from the accelerated failure time model of buy and sell limit orders in the pooled sample of August 2000 are shown in *Table 3.4*. The table also includes the estimations' standard errors and z-statistics.

The estimates of *PRICEGAP* show consistent positive and significant values across all three types of order events for limit buy and sell orders. This suggests that the time to a limit order event (order execution, revision or cancellation) is expected to be longer the further the limit price is placed from the mid-quote price. Not only that these orders take longer to be picked up, the traders also tend to be more patient when they place the limit orders further away from the quoted price. The parameter estimates of *INITRADE* are positive for buy limit orders. This is consistent with the view that a shorter time-to-execution is expected for a buy limit order if the previous transaction is seller-initiated. On the other hand, if the prior transaction is a buyer-initiated trade, a shorter time-to-execution is expected for a sell limit order. This is exactly what the negative signs on *INITRADE* show for sell limit orders. The same interpretations can be made for time-to-revision and time-to-cancellation.

Table 3.4: Single-Spell Survival Analysis of Limit Order Durations in the Pooled Sample

This table presents the parameter estimates for the single-spell survival analysis of the determinants of limit order duration in the pooled sample of August 2000. The estimation model used in this analysis is the Accelerated Failure Time model for limit order times. The study is conducted separately for limit order execution times, revision times and cancellation times. Definitions of the explanatory variables are given in the text. The regression results, including parameter estimates, standard errors and z-statistics are reported separately for buy and sell limit orders.

	Time-to-Execution			**Time-to-Revision**			**Time-to-Cancellation**		
	Estimate	*Std. Err.*	*z*	*Estimate*	*Std. Err.*	*z*	*Estimate*	*Std. Err.*	*z*
Buy Limit Orders									
PRICEGAP	1.551	0.853	1.820	1.297	0.560	2.310	1.183	0.628	1.880
INITRADE	0.162	0.023	6.950	0.151	0.020	7.580	0.148	0.020	7.520
SSLIQUIDITY	0.091	0.009	9.780	0.161	0.010	16.710	0.147	0.009	16.100
MKDPR	-0.006	0.008	-0.780	-0.010	0.004	-2.740	-0.010	0.004	-2.370
OSLIQUIDITY	0.075	0.026	2.910	-0.007	0.028	-0.250	-0.001	0.027	-0.040
ORDSIZE	-0.249	0.040	-6.180	-0.133	0.028	-4.760	-0.102	0.026	-3.940
Constant	1.906	0.535	3.560	0.704	0.446	1.580	0.326	0.404	0.810
Sell Limit Orders									
PRICEGAP	2.731	0.446	6.130	1.349	0.477	2.830	1.447	0.467	3.100
INITRADE	-0.101	0.026	-3.810	-0.096	0.025	-3.830	-0.093	0.025	-3.740
SSLIQUIDITY	0.089	0.005	16.450	0.160	0.007	23.500	0.156	0.007	22.710
MKDPR	0.001	0.000	5.480	0.001	0.000	3.620	0.001	0.000	4.630
OSLIQUIDITY	0.049	0.029	1.660	-0.038	0.029	-1.280	-0.033	0.029	-1.130
ORDSIZE	-0.344	0.047	-7.270	-0.195	0.039	-4.980	-0.176	0.031	-5.700
Constant	2.979	0.583	5.110	1.430	0.506	2.830	1.224	0.416	2.940

The *SSLIQUIDITY* parameter estimates indicate the relationship between the time-to-an-order-event and the same-side market depth. As predicted, positive signs of the estimates are attained in both samples of buy and sell limit orders. For the case of limit order executions, the positive sign of *SSLIQUIDITY* reiterates the basic economic explanation of supply and demand in the market. Limit orders, for both buy and sell sides, are expected to take a longer time to be executed if there is a larger supply of same-side orders in the limit order book. When there is an increase of same-side supply of limit orders, traders are also more reluctant to revise or cancel their limit orders. The estimates of *OSLIQUIDITY* show a negative and significant relationship between opposite-side liquidity and duration of order revision and cancellation. The results seem to suggest that when the market is more liquid, the submitted limit orders tend to take a shorter time to be revised or cancelled. This is attributable to the fact that when the market becomes more liquid, traders tend to revise their limit orders quicker in order to increase their chance of execution. This is somewhat consistent with the findings of Hasbrouck and Saar (2009) which suggest that traders tend to 'chase the market' when quotes are improved. As an alternative, they can also cancel their limit order and resubmit a market order as it might take a very long time for patient limit orders to be executed (as shown by a positive relationship between *OSLIQUIDITY* and time-to-execution of limit orders). This observation is supportive of the basic trade-off proposed by Cohen et al. (1981) which suggest that the 'gravitational pull' of immediate execution using a market order increases when the level of liquidity increases[5].

The *ORDSIZE* parameter estimates are significantly negative for both buy and sell limit orders. This result suggests that larger orders have shorter time-to-an-order-event. Larger limit orders are known to be associated with higher opportunity costs.

[5] This is known in the literature as the 'cost of immediacy hypothesis'.

Therefore traders who submit a limit order with a larger scale are likely to prefer the orders to be executed quicker. As a result, they normally set a limit price and choose certain market conditions which are most suitable for their orders to be executed, hence a shorter time-to-execution. It should also be noted that, in this study, only the time-to-first-fill is considered. Even though orders with larger size tend to be executed quicker, there is no guarantee that they will be fully filled. As a larger order has a higher opportunity cost, traders also tend to move quicker in revising or cancelling their orders should the orders stay unexecuted, hence a shorter time-to-revision or a shorter time-to-cancellation. The consistent negative signs of the *ORDSIZE* parameter estimates for all three order event times, namely, time-to-execution, time-to-revision, and time-to-cancellation, have shown and confirmed the above intuition.

Survival analysis is also carried out separately on samples of large-cap and small-cap stocks by estimating a single-spell duration model. *Table 3.5* presents the parameter estimation results for large-cap stocks and *Table 3.6* reports the parameter estimation results for small-cap stocks. The results are mostly consistent with the pooled sample and the coefficient estimates can also be interpreted in a similar way. However, there are some exceptions in the sample of small-cap stocks. The coefficient estimates of *OSLIQUIDITY* are positive instead of negative for time-to-revision and time-to-cancellation. However, both of these effects are not statistically significant.

Table 3.5: Single-Spell Survival Analysis of Limit Order Durations in the Sample of Large Stocks

This table presents the parameter estimates for the single-spell survival analysis of the determinants of limit order duration in the sample of large-cap stocks in August 2000. The estimation model used in this analysis is the Accelerated Failure Time model for limit order times. The study is conducted separately for limit order execution times, revision times and cancellation times. Definitions of the explanatory variables are given in the text. The regression results, including parameter estimates, standard errors and z-statistics are reported separately for buy and sell limit orders.

	Time-to-Execution			**Time-to-Revision**			**Time-to-Cancellation**		
	Estimate	*Std. Err.*	*z*	*Estimate*	*Std. Err.*	*z*	*Estimate*	*Std. Err.*	*z*
Buy Limit Orders									
PRICEGAP	1.526	1.031	1.480	1.155	0.520	2.220	1.130	0.591	1.910
INITRADE	0.139	0.024	5.760	0.128	0.022	5.880	0.121	0.022	5.600
SSLIQUIDITY	0.089	0.012	7.530	0.158	0.012	12.870	0.144	0.011	12.670
MKDPR	-0.007	0.010	-0.680	-0.009	0.003	-2.670	-0.010	0.004	-2.300
OSLIQUIDITY	0.046	0.022	2.130	-0.031	0.020	-1.550	-0.025	0.019	-1.350
ORDSIZE	-0.257	0.042	-6.090	-0.138	0.029	-4.830	-0.111	0.026	-4.260
Constant	1.983	0.484	4.100	0.731	0.391	1.870	0.407	0.342	1.190
Sell Limit Orders									
PRICEGAP	3.687	0.470	7.850	3.930	1.810	2.170	1.745	0.456	3.830
INITRADE	-0.124	0.029	-4.210	-0.123	0.029	-4.240	-0.110	0.028	-4.000
SSLIQUIDITY	0.093	0.006	15.350	0.164	0.009	17.960	0.155	0.007	21.970
MKDPR	0.002	0.000	7.450	0.003	0.001	2.280	0.001	0.000	5.510
OSLIQUIDITY	0.022	0.018	1.200	-0.054	0.019	-2.820	-0.056	0.018	-3.070
ORDSIZE	-0.401	0.048	-8.410	-0.227	0.037	-6.160	-0.210	0.032	-6.500
Constant	3.557	0.519	6.850	1.810	0.416	4.350	1.459	0.358	4.070

Table 3.6: Single-Spell Survival Analysis of Limit Order Durations in the Sample of Small Stocks

This table presents the parameter estimates for the single-spell survival analysis of the determinants of limit order duration in the sample of small-cap stocks in August 2000. The estimation model used in this analysis is the Accelerated Failure Time model for limit order times. The study is conducted separately for limit order execution times, revision times and cancellation times. Definitions of the explanatory variables are given in the text. The regression results, including parameter estimates, standard errors and z-statistics are reported separately for buy and sell limit orders.

	Time-to-Execution			**Time-to-Revision**			**Time-to-Cancellation**		
	Estimate	*Std. Err.*	*z*	*Estimate*	*Std. Err.*	*z*	*Estimate*	*Std. Err.*	*z*
Buy Limit Orders									
PRICEGAP	7.027	0.530	13.260	9.179	1.100	8.340	10.011	1.350	7.420
INITRADE	0.160	0.041	3.900	0.158	0.039	4.100	0.205	0.040	5.110
SSLIQUIDITY	0.079	0.011	7.050	0.134	0.012	11.620	0.128	0.012	10.320
MKDPR	-0.165	0.015	-11.130	-0.233	0.022	-10.640	-0.257	0.027	-9.630
OSLIQUIDITY	0.091	0.036	2.530	0.002	0.024	0.090	0.018	0.025	0.720
ORDSIZE	-0.214	0.053	-4.050	-0.129	0.041	-3.120	-0.071	0.041	-1.730
Constant	3.228	0.592	5.450	2.545	0.567	4.490	1.726	0.513	3.370
Sell Limit Orders									
PRICEGAP	1.556	0.292	5.320	0.631	0.802	0.790	1.319	1.934	0.680
INITRADE	-0.052	0.029	-1.790	-0.049	0.034	-1.440	-0.039	0.033	-1.150
SSLIQUIDITY	0.082	0.010	8.420	0.144	0.014	10.650	0.133	0.014	9.510
MKDPR	0.000	0.000	0.250	0.001	0.001	1.410	0.001	0.001	0.950
OSLIQUIDITY	0.067	0.020	3.410	-0.064	0.024	-2.600	-0.043	0.027	-1.620
ORDSIZE	-0.289	0.042	-6.870	-0.132	0.033	-3.970	-0.120	0.036	-3.320
Constant	4.126	0.448	9.210	2.992	0.419	7.140	2.644	0.453	5.830

3.4.3. Survival Analysis with a Multiple-Spell Duration Model

This thesis is perhaps the first research that examines the determinants of dynamic limit order placement strategies using survival analysis with a multiple-spell duration model. *Table 3.7* presents the results for the multiple-spell duration analysis of buy limit orders in the pooled sample of the initial period (August 2000). Meanwhile, *Table 3.8* reports the results for the multiple-spell duration analysis of sell limit orders in the same sample. This study describes limit order dynamics as sequences of multiple limit order events. The estimation model used in this analysis is the Proportional Hazard model under the exponential distribution for limit order times. The coefficient estimates and their significance levels are presented for each of the variable and the standard errors are reported in the parentheses.

The first explanatory variable of interest is *PRICEGAP*. This estimate is mostly negative and significant for all order spells in both samples of buy limit orders and sell limit orders. The result implies a negative relationship between the hazard rate of order events and the distance from the limit price to the mid-quote price. In other words, the closer the limit price is placed from the mid-quote (i.e. the smaller *PRICEGAP*), the higher the probability of transition from one event to another. Fong and Liu (2010) suggest that traders do monitor their limit orders closely and this is especially true when a limit order is submitted with a more aggressive price. The incentives for monitoring come from the fact that limit orders are subject to submission risks, including non-execution (NE) and free-option (FO) risks. In addition, the monitoring cost of limit orders is also a critical factor that impacts the level of revision and cancellation activities. As a result, limit orders have a higher chance to be executed, revised or cancelled when being placed more aggressively.

Table 3.7: Multiple-Spell Duration Analysis of Buy Limit Orders in the Pooled Sample of the Initial Period (August 2000)

This table presents the results for the multiple-spell duration survival analysis of buy limit orders in the pooled sample of the initial period of August 2000. The table describes the study of limit order dynamics as a sequence of multiple limit order events. The estimation model used in this survival analysis is the Proportional Hazard model under the exponential distribution for limit order times. Definitions of the explanatory variables are given in the text. Panel A reports the results for limit order executions (including full and partial), limit order revisions and limit order cancellations that followed a limit order submission. Panel B presents the results for the limit order events that followed a limit order revision and Panel C reports the results for the limit order events that followed a limit order partial execution. The coefficient estimates are presented for each of the variable and the standard errors are reported in the parentheses. ***, **, * denote statistical significance at the 1, 5 and 10 percent level, respectively.

Panel A

ORIGIN	**Submission**			
DESTINATION	***Full Execution***	***Partial Execution***	***Revision***	***Cancellation***
PRICEGAP	-0.737***	-0.437***	-0.216*	-0.104
	(0.032)	(0.031)	(0.114)	(0.140)
INITRADE	-0.353***	-0.278***	-0.152***	-0.206***
	(0.015)	(0.019)	(0.014)	(0.022)
SSLIQUIDITY	-0.790***	-0.513***	-0.521***	-0.710***
	(0.015)	(0.015)	(0.022)	(0.044)
MKDPR	0.038	-0.045***	0.562***	0.463***
	(0.035)	(0.017)	(0.114)	(0.168)
OSLIQUIDITY	-0.079***	-0.059***	0.082***	0.015
	(0.014)	(0.016)	(0.015)	(0.025)
ORDSIZE	0.140***	0.299***	0.132***	0.367***
	(0.013)	(0.051)	(0.038)	(0.067)
CONST	-1.073***	-0.159***	-1.380***	-1.960***
	(0.016)	(0.042)	(0.017)	(0.029)
UNOBHET	0.110***	0.053***	0.047***	0.246***
	(0.014)	(0.018)	(0.017)	(0.023)

Panel B

ORIGIN	**Revision**				**Partial Execution**			
DESTINATION	***Full Execution***	***Partial Execution***	***Revision***	***Cancellation***	***Full Execution***	***Partial Execution***	***Revision***	***Cancellation***
PRICEGAP	-0.347***	-0.304***	0.084	-0.680***	0.005	-0.035***	-0.140***	0.070
	(0.042)	(0.038)	(0.079)	(0.189)	(0.012)	(0.010)	(0.028)	(0.044)
INITRADE	-0.343***	-0.178***	-0.098***	-0.135***	-0.172***	-0.125***	-0.110***	-0.204***
	(0.033)	(0.035)	(0.021)	(0.043)	(0.013)	(0.012)	(0.030)	(0.044)
SSLIQUIDITY	-0.569***	-0.494***	-0.403***	-0.184***	0.014	-0.055***	-0.360***	-0.040
	(0.031)	(0.033)	(0.031)	(0.049)	(0.012)	(0.010)	(0.025)	(0.041)
MKDPR	-0.049	-0.070**	0.125**	0.587***	0.072***	0.057***	-0.036	0.025
	(0.043)	(0.034)	(0.060)	(0.227)	(0.013)	(0.012)	(0.031)	(0.040)
OSLIQUIDITY	-0.005	-0.077***	0.018	-0.079*	0.383***	0.239***	0.702***	0.711***
	(0.024)	(0.026)	(0.022)	(0.047)	(0.033)	(0.028)	(0.073)	(0.105)
ORDSIZE	0.130*	0.158*	0.115**	0.025	-0.117***	-0.107***	-0.224***	-0.207**
	(0.073)	(0.082)	(0.045)	(0.071)	(0.031)	(0.028)	(0.070)	(0.100)
PREVDUR	-0.007***	-0.009***	-0.009***	-0.006***	-0.007***	-0.007***	-0.008***	-0.014***
	(0.001)	(0.001)	(0.001)	(0.001)	(<.001)	(<.001)	(0.001)	(0.002)
CONST	0.054	0.150**	-1.044***	-1.820***	0.929***	0.557***	-0.274***	-0.518***
	(0.093)	(0.062)	(0.028)	(0.058)	(0.012)	(0.011)	(0.027)	(0.045)
UNOBHET	-0.045	-0.113***	-0.134***	-0.009	0.109***	-0.092***	0.146***	0.298***
	(0.033)	(0.034)	(0.029)	(0.053)	(0.010)	(0.011)	(0.023)	(0.035)

Table 3.8: Multiple-Spell Duration Analysis of Sell Limit Orders in the Pooled Sample of the Initial Period (August 2000)

This table presents the results for the multiple-spell duration survival analysis of sell limit orders in the pooled sample of the initial period of August 2000. The table describes the study of limit order dynamics as a sequence of multiple limit order events. The estimation model used in this survival analysis is the Proportional Hazard model under the exponential distribution for limit order times. Definitions of the explanatory variables are given in the text. Panel A reports the results for limit order executions (including full and partial), limit order revisions and limit order cancellations that followed a limit order submission. Panel B presents the results for the limit order events that followed a limit order revision and Panel C reports the results for the limit order events that followed a limit order partial execution. The coefficient estimates are presented for each of the variable and the standard errors are reported in the parentheses. ***, **, * denote statistical significance at the 1, 5 and 10 percent level respectively.

Panel A

ORIGIN	**Submission**			
DESTINATION	***Full Execution***	***Partial Execution***	***Revision***	***Cancellation***
PRICEGAP	-0.927***	-3.690***	-3.500***	-0.980***
	(0.032)	(0.220)	(0.232)	(0.286)
INITRADE	0.358***	0.269***	0.065***	0.114***
	(0.015)	(0.018)	(0.016)	(0.024)
SSLIQUIDITY	-0.797***	-0.576***	-0.124***	-1.616***
	(0.014)	(0.015)	(0.005)	(0.107)
MKDPR	-0.242***	-0.038**	-0.003***	-2.339***
	(0.034)	(0.018)	(<.001)	(0.252)
OSLIQUIDITY	-0.099***	-0.030*	-0.004	0.056**
	(0.014)	(0.016)	(0.008)	(0.027)
ORDSIZE	0.166***	0.482***	0.101***	0.164
	(0.013)	(0.051)	(0.011)	(0.138)
CONST	-1.141***	-0.116***	-1.260***	-1.799***
	(0.016)	(0.042)	(0.098)	(0.030)
UNOBHET	0.087***	0.103***	0.090***	0.267***
	(0.015)	(0.017)	(0.018)	(0.025)

Panel B

ORIGIN	**Revision**				**Partial Execution**			
DESTINATION	***Full Execution***	***Partial Execution***	***Revision***	***Cancellation***	***Full Execution***	***Partial Execution***	***Revision***	***Cancellation***
PRICEGAP	-3.033***	-0.196***	-2.460***	-1.563**	0.006	-0.052***	-0.144***	0.036
	(0.265)	(0.038)	(0.231)	(0.742)	(0.012)	(0.011)	(0.029)	(0.045)
INITRADE	0.308***	0.114***	0.039*	0.109**	0.132***	0.141***	0.128***	0.113**
	(0.036)	(0.036)	(0.023)	(0.049)	(0.013)	(0.011)	(0.030)	(0.055)
SSLIQUIDITY	-0.611***	-0.433***	-0.538***	-0.072***	0.069***	0.108***	-0.417***	-0.144***
	(0.034)	(0.035)	(0.038)	(0.018)	(0.013)	(0.011)	(0.027)	(0.044)
MKDPR	0.020	0.150***	-2.483***	-0.001***	-0.094***	-0.099***	-0.053*	0.006
	(0.038)	(0.029)	(0.224)	(<.001)	(0.014)	(0.012)	(0.031)	(0.058)
OSLIQUIDITY	-0.037	-0.035	-0.134***	-0.025	0.359***	0.270***	0.616***	0.881***
	(0.025)	(0.028)	(0.026)	(0.025)	(0.034)	(0.029)	(0.081)	(0.127)
ORDSIZE	0.121	0.001	0.411***	-0.042	-0.102***	-0.092***	-0.124	-0.315***
	(0.077)	(0.086)	(0.062)	(0.038)	(0.033)	(0.028)	(0.077)	(0.121)
PREVDUR	-0.006***	-0.008***	-0.007***	-0.006***	-0.009***	-0.011***	-0.009***	-0.016***
	(<.001)	(0.001)	(<.001)	(0.001)	(<.001)	(<.001)	(0.001)	(0.002)
CONST	0.226**	0.081	-1.060***	-0.564*	0.940***	0.658***	-0.259***	-0.446***
	(0.095)	(0.062)	(0.031)	(0.335)	(0.012)	(0.011)	(0.029)	(0.050)
UNOBHET	-0.027	-0.098***	-0.052*	0.081	0.123***	-0.007	0.212***	0.357***
	(0.033)	(0.035)	(0.030)	(0.054)	(0.010)	(0.011)	(0.024)	(0.037)

The coefficient estimates of *INITRADE* for buy limit orders are all significantly negative, whereas those for sell limit orders are all significantly positive. Similar to the previous findings, this result suggests that if the previous transaction is a seller-initiated trade, then a buy limit order tends to experience a higher probability of execution (both full and partial), as well as revision and cancellation. On the other hand, a sell limit order is likely to experience a higher chance of execution, revision or cancellation if the prior transaction is a buyer initiated trade.

Two different types of liquidity are measured by the two explanatory variables *SSLIQUIDITY* and *OSLIQUIDITY*. The variable *SSLIQUIDITY* shows the relationship between the same-side depth of the limit order book and the hazard rate of order events. The results are mostly negative and significant for both buy limit orders and sell limit orders. This negative relationship suggests that the deeper the limit order book on the same-side, the lower the probability of transition to the subsequent order events. This result is expected from the supply-demand standpoint. As the limit order book receives more supply of same-side orders, the existing limit orders can find it harder to be executed. These existing limit orders also have a lower probability of being revised or cancelled, as predicted by negative and significant estimates of the variable *SSLIQUIDITY*.

The estimates of *OSLIQUIDITY* show some differences in the results among the categories of submission, revision and execution, for both buy and sell limit orders. The coefficient estimates are generally positive and significant for spells that transit to an order revision. The effect, however, is stronger for buy limit orders than sell limit orders. This result is in line with the view that as the opposite-side liquidity improves, traders revise their limit orders to ‘chase the market’ and try to gain a better execution rate. Consequently, it results in a higher probability of transition into limit order revisions. Moreover, the significantly positive relationship between the opposite-side liquidity and the intensity of limit order cancellation is also observed, especially for orders originating from submission or partial execution. This result lends strong support for the theory proposed by Cohen et al. (1981), which suggests that when the cost of immediate execution drops, traders would be more eager in cancelling their limit order to opt for submission of a market order.

Regarding the order characteristic measures, the *ORDSIZE* estimates are mostly positive and significant for both buy and sell limit orders, except in the category of orders originating from partial execution. This result indicates that the limit order with a larger size has a higher probability of being executed, revised or cancelled following its previous submission or revision. The limit order, however, has a lower chance to be transited to the three order events if it has been remained in the limit order book as a result from a partial execution. The results observed for *ORDSIZE* confirm the intuition regarding opportunity costs of large orders. Limit orders submitted with a larger size tend to be monitored more closely since the cost of non-execution is higher than that of smaller orders (see, for example, Fong and Liu, 2010). As a result, a larger order is often submitted with a selective price and market condition to maximise execution rate. If the large limit order is not successfully executed, traders would revise the order, or cancel and submit a market order to improve the chance of execution.

The coefficient estimates of the duration dependence variable, *PREVDUR*, are negative and significant across limit order events that are originated from both limit order revision and partial execution. This result suggests that the longer the limit order's previous duration, the lower the probability of transiting to its destination states. In other words, limit orders which spend more time in the previous spells tend to have a smaller chance of being executed, revised or cancelled. This result could be explained by a labour economics' perspective when observing lagged duration dependence variables in survival analysis with multiple-spell duration. For example, Van Ours (2004) suggests that workers start reducing their job search intensity if the subsidised job lasts too long. This is evidenced by a significantly negative coefficient estimate for the lagged duration dependence variable found in labour economics literature. Similarly, if the revised or partially executed order stays in the limit order book for an extended period, traders tend to be demotivated in taking additional action on the order. As a result, a lower probability of execution, revision or cancellation is expected.

The coefficient estimates of *UNOBHET*, the unobserved heterogeneity term, are consistent in the two samples of buy and sell limit orders. The estimates are generally positive and significant for the order spells that are originated from limit order submission and partial execution, while being negative and significant for spells that are originated from limit order revision. This observation implies that there are other unobserved factors that have positive effects on the hazard rate of spells originating from order submission and partial execution. At the same time, there are also unobserved factors that have negative effects on the hazard rate of spells which come from limit order revision. Traders' preferences, own objectives and others could contribute to these unobserved factors.

For completeness, survival analysis with multiple-spell duration is also conducted for samples of large-cap and small-cap stocks. *Table 3.9* and *Table 3.11* present the estimation results for buy limit orders, whereas *Table 3.10* and *Table 3.12* report the estimation results for sell limit orders for large and small stocks, respectively.

Table 3.9: Multiple-Spell Duration Analysis of Buy Limit Orders of Large-Cap Stocks in the Initial Sample Period (August 2000)

This table presents the results for the multiple-spell duration survival analysis of buy limit orders in the sample of large capitalisation stocks in the initial period of August 2000. The table describes the study of limit order dynamics as a sequence of multiple limit order events. The estimation model used in this survival analysis is the Proportional Hazard model under the exponential distribution for limit order times. Definitions of the explanatory variables are given in the text. Panel A reports the results for limit order executions (including full and partial), limit order revisions and limit order cancellations that followed a limit order submission. Panel B presents the results for the limit order events that followed a limit order revision and Panel C reports the results for the limit order events that followed a limit order partial execution. The coefficient estimates are presented for each of the variable and the standard errors are reported in the parentheses. ***, **, * denote statistical significance at the 1, 5 and 10 percent level, respectively.

Panel A

ORIGIN	**Submission**			
DESTINATION	***Full Execution***	***Partial Execution***	***Revision***	***Cancellation***
PRICEGAP	-0.784***	-0.458***	-0.246**	0.111
	(0.035)	(0.034)	(0.118)	(0.153)
INITRADE	-0.355***	-0.250***	-0.120***	-0.168***
	(0.015)	(0.019)	(0.015)	(0.025)
SSLIQUIDITY	-0.814***	-0.510***	-0.573***	-0.708***
	(0.015)	(0.015)	(0.024)	(0.054)
MKDPR	0.016	-0.061***	0.493***	0.265
	(0.038)	(0.018)	(0.119)	(0.175)
OSLIQUIDITY	-0.028*	-0.022	0.117***	0.113***
	(0.015)	(0.016)	(0.016)	(0.028)
ORDSIZE	0.208***	0.382***	0.386***	0.343***
	(0.014)	(0.052)	(0.044)	(0.078)
CONST	-0.960***	-0.042	-1.304***	-1.702***
	(0.016)	(0.043)	(0.018)	(0.032)
UNOBHET	0.030*	-0.011	0.003	0.278***
	(0.016)	(0.020)	(0.018)	(0.025)

Panel B

ORIGIN	**Revision**				**Partial Execution**			
DESTINATION	***Full Execution***	***Partial Execution***	***Revision***	***Cancellation***	***Full Execution***	***Partial Execution***	***Revision***	***Cancellation***
PRICEGAP	-0.388***	-0.321***	-0.006	-0.589***	0.001	-0.019*	-0.141***	0.076*
	(0.045)	(0.041)	(0.096)	(0.136)	(0.012)	(0.010)	(0.030)	(0.046)
INITRADE	-0.342***	-0.178***	-0.095***	-0.090*	-0.187***	-0.138***	-0.113***	-0.213***
	(0.034)	(0.036)	(0.022)	(0.046)	(0.013)	(0.012)	(0.032)	(0.045)
SSLIQUIDITY	-0.637***	-0.522***	-0.417***	-0.182***	0.005	-0.029***	-0.320***	-0.039
	(0.033)	(0.034)	(0.033)	(0.052)	(0.012)	(0.010)	(0.026)	(0.041)
MKDPR	-0.050	-0.073*	0.178**	0.427***	0.067***	0.057***	-0.028	0.023
	(0.047)	(0.037)	(0.076)	(0.132)	(0.013)	(0.012)	(0.032)	(0.041)
OSLIQUIDITY	0.019	-0.043	0.039*	-0.099**	0.416***	0.287***	0.683***	0.710***
	(0.024)	(0.027)	(0.023)	(0.050)	(0.033)	(0.028)	(0.076)	(0.110)
ORDSIZE	0.268***	0.227***	0.178***	0.023	-0.087***	-0.103***	-0.196***	-0.174*
	(0.075)	(0.085)	(0.049)	(0.062)	(0.032)	(0.028)	(0.074)	(0.105)
PREVDUR	-0.006***	-0.008***	-0.009***	-0.008***	-0.005***	-0.006***	-0.008***	-0.014***
	(0.001)	(0.001)	(0.001)	(0.001)	(<.001)	(<.001)	(0.001)	(0.002)
CONST	0.008	0.254***	-1.010***	-1.742***	0.988***	0.598***	-0.270***	-0.497***
	(0.093)	(0.063)	(0.029)	(0.061)	(0.012)	(0.011)	(0.028)	(0.046)
UNOBHET	-0.119***	-0.144***	-0.178***	0.013	-0.045***	-0.200***	0.050*	0.265***
	(0.036)	(0.037)	(0.031)	(0.055)	(0.012)	(0.012)	(0.027)	(0.037)

Table 3.10: Multiple-Spell Duration Analysis of Sell Limit Orders of Large-Cap Stocks in the Initial Sample Period (August 2000)

This table presents the results for the multiple-spell duration survival analysis of sell limit orders in the sample of large capitalisation stocks in the initial period of August 2000. The table describes the study of limit order dynamics as a sequence of multiple limit order events. The estimation model used in this survival analysis is the Proportional Hazard model under the exponential distribution for limit order times. Definitions of the explanatory variables are given in the text. Panel A reports the results for limit order executions (including full and partial), limit order revisions and limit order cancellations that followed a limit order submission. Panel B presents the results for the limit order events that followed a limit order revision and Panel C reports the results for the limit order events that followed a limit order partial execution. The coefficient estimates are presented for each of the variable and the standard errors are reported in the parentheses. ***, **, * denote statistical significance at the 1, 5 and 10 percent level, respectively.

Panel A

ORIGIN	**Submission**			
DESTINATION	***Full Execution***	***Partial Execution***	***Revision***	***Cancellation***
PRICEGAP	-0.984***	-3.839***	-2.111***	-0.715***
	(0.035)	(0.263)	(0.098)	(0.072)
INITRADE	0.383***	0.278***	0.074***	0.140***
	(0.016)	(0.020)	(0.016)	(0.026)
SSLIQUIDITY	-0.761***	-0.556***	-0.499***	-0.490***
	(0.014)	(0.016)	(0.021)	(0.033)
MKDPR	-0.233***	-0.013	-1.945***	-0.812***
	(0.037)	(0.022)	(0.094)	(0.062)
OSLIQUIDITY	-0.009	0.034**	0.022	0.025
	(0.014)	(0.016)	(0.017)	(0.028)
ORDSIZE	0.238***	0.644***	0.425***	0.005
	(0.014)	(0.052)	(0.038)	(0.036)
CONST	-1.019***	-0.097**	-1.406***	-1.661***
	(0.016)	(0.044)	(0.020)	(0.032)
UNOBHET	0.020	0.010	0.021	0.239***
	(0.016)	(0.020)	(0.020)	(0.027)

Panel B

ORIGIN	**Revision**				**Partial Execution**			
DESTINATION	***Full Execution***	***Partial Execution***	***Revision***	***Cancellation***	***Full Execution***	***Partial Execution***	***Revision***	***Cancellation***
PRICEGAP	-3.202***	-0.187***	-3.033***	-1.438*	0.003	-0.038***	-0.135***	0.013
	(0.301)	(0.040)	(0.283)	(0.821)	(0.012)	(0.011)	(0.030)	(0.046)
INITRADE	0.301***	0.125***	0.054**	0.141***	0.170***	0.176***	0.108***	0.126**
	(0.038)	(0.037)	(0.024)	(0.052)	(0.014)	(0.012)	(0.032)	(0.056)
SSLIQUIDITY	-0.619***	-0.467***	-0.578***	-0.091***	0.086***	0.163***	-0.407***	-0.150***
	(0.035)	(0.036)	(0.042)	(0.019)	(0.013)	(0.011)	(0.029)	(0.046)
MKDPR	0.068*	0.158***	-2.992***	-0.001***	-0.097***	-0.104***	-0.036	0.007
	(0.041)	(0.030)	(0.275)	(<.001)	(0.015)	(0.013)	(0.032)	(0.060)
OSLIQUIDITY	-0.002	-0.004	-0.105***	0.002	0.386***	0.279***	0.588***	0.938***
	(0.025)	(0.029)	(0.026)	(0.026)	(0.035)	(0.029)	(0.084)	(0.128)
ORDSIZE	0.268***	0.218**	0.529***	-0.060	-0.094***	-0.048*	-0.089	-0.340***
	(0.080)	(0.087)	(0.068)	(0.040)	(0.033)	(0.028)	(0.080)	(0.123)
PREVDUR	-0.005***	-0.007***	-0.006***	-0.006***	-0.007***	-0.009***	-0.008***	-0.016***
	(0.001)	(0.001)	(<.001)	(0.001)	(<.001)	(<.001)	(0.001)	(0.002)
CONST	0.160	0.064	-0.984***	-0.364	1.016***	0.732***	-0.233***	-0.389***
	(0.097)	(0.063)	(0.033)	(0.361)	(0.012)	(0.011)	(0.031)	(0.052)
UNOBHET	-0.089**	-0.214***	-0.130***	0.073	-0.003	-0.119***	0.111***	0.315***
	(0.037)	(0.041)	(0.033)	(0.057)	(0.012)	(0.012)	(0.027)	(0.039)

Table 3.11: Multiple-Spell Duration Analysis of Buy Limit Orders of Small-Cap Stocks in the Initial Sample Period (August 2000)

This table presents the results for the multiple-spell duration survival analysis of buy limit orders in the sample of small capitalisation stocks in the initial period of August 2000. The table describes the study of limit order dynamics as a sequence of multiple limit order events. The estimation model used in this survival analysis is the Proportional Hazard model under the exponential distribution for limit order times. Definitions of the explanatory variables are given in the text. Panel A reports the results for limit order executions (including full and partial), limit order revisions and limit order cancellations that followed a limit order submission. Panel B presents the results for the limit order events that followed a limit order revision and Panel C reports the results for the limit order events that followed a limit order partial execution. The coefficient estimates are presented for each of the variable and the standard errors are reported in the parentheses. ***, **, * denote statistical significance at the 1, 5 and 10 percent level, respectively.

Panel A

ORIGIN	**Submission**			
DESTINATION	***Full Execution***	***Partial Execution***	***Revision***	***Cancellation***
PRICEGAP	-0.314***	-0.247***	-0.606***	-0.520***
	(0.063)	(0.063)	(0.098)	(0.108)
INITRADE	-0.258***	-0.273***	-0.259***	-0.146***
	(0.037)	(0.045)	(0.037)	(0.040)
SSLIQUIDITY	-0.680***	-0.454***	-0.280***	-0.401***
	(0.039)	(0.038)	(0.042)	(0.048)
MKDPR	-0.073	-0.015	0.786***	0.465***
	(0.067)	(0.040)	(0.084)	(0.104)
OSLIQUIDITY	-0.008	0.003	0.043	0.029
	(0.041)	(0.048)	(0.043)	(0.052)
ORDSIZE	0.027	0.196	-0.484***	-0.128***
	(0.034)	(0.152)	(0.041)	(0.049)
CONST	-2.448***	-1.682***	-2.079***	-3.323***
	(0.040)	(0.130)	(0.043)	(0.056)
UNOBHET	-0.325***	-0.298***	-0.107**	-0.469***
	(0.052)	(0.060)	(0.047)	(0.085)

Panel B

ORIGIN	**Revision**				**Partial Execution**			
DESTINATION	***Full Execution***	***Partial Execution***	***Revision***	***Cancellation***	***Full Execution***	***Partial Execution***	***Revision***	***Cancellation***
PRICEGAP	-0.165*	-0.128	-2.183***	-1.424	0.116***	-0.105***	-0.113	-0.170
	(0.094)	(0.097)	(0.488)	(1.359)	(0.038)	(0.035)	(0.074)	(0.163)
INITRADE	-0.285***	-0.117	-0.139**	-0.286***	-0.218***	-0.101**	-0.175**	-0.156
	(0.090)	(0.090)	(0.064)	(0.107)	(0.043)	(0.045)	(0.089)	(0.209)
SSLIQUIDITY	-0.339***	-0.465***	-0.376***	-0.134	0.085**	-0.068*	-0.751***	-0.229
	(0.071)	(0.083)	(0.083)	(0.140)	(0.040)	(0.037)	(0.078)	(0.192)
MKDPR	-0.090	-0.114	2.510***	2.455*	0.074	0.022	-0.102	0.074
	(0.061)	(0.071)	(0.480)	(1.366)	(0.045)	(0.046)	(0.085)	(0.202)
OSLIQUIDITY	-0.010	-0.024	-0.068	0.114	0.499***	0.102	1.133***	0.689**
	(0.074)	(0.072)	(0.071)	(0.135)	(0.098)	(0.086)	(0.209)	(0.317)
ORDSIZE	-0.137	0.583**	-0.167	-0.806***	-0.311***	0.098	-0.389**	-0.336
	(0.218)	(0.252)	(0.102)	(0.311)	(0.092)	(0.082)	(0.195)	(0.283)
PREVDUR	-0.005***	-0.005***	-0.005***	-0.002	-0.005***	-0.003***	-0.002	-0.007*
	(0.001)	(0.001)	(0.001)	(0.002)	(0.001)	(0.001)	(0.002)	(0.003)
CONST	-0.809**	-1.420***	-1.611***	-2.438***	-0.503***	-0.810***	-0.559***	-1.145***
	(0.343)	(0.189)	(0.093)	(0.159)	(0.040)	(0.041)	(0.080)	(0.193)
UNOBHET	-0.273**	-0.483***	-0.109	-0.445**	0.107***	-0.124***	0.389***	0.365***
	(0.118)	(0.116)	(0.092)	(0.199)	(0.034)	(0.041)	(0.056)	(0.136)

Table 3.12: Multiple-Spell Duration Analysis of Sell Limit Orders of Small-Cap Stocks in the Initial Sample Period (August 2000)

This table presents the results for the multiple-spell duration survival analysis of sell limit orders in the sample of small capitalisation stocks in the initial period of August 2000. The table describes the study of limit order dynamics as a sequence of multiple limit order events. The estimation model used in this survival analysis is the Proportional Hazard model under the exponential distribution for limit order times. Definitions of the explanatory variables are given in the text. Panel A reports the results for limit order executions (including full and partial), limit order revisions and limit order cancellations that followed a limit order submission. Panel B presents the results for the limit order events that followed a limit order revision and Panel C reports the results for the limit order events that followed a limit order partial execution. The coefficient estimates are presented for each of the variable and the standard errors are reported in the parentheses. ***, **, * denote statistical significance at the 1, 5 and 10 percent level, respectively.

Panel A

ORIGIN	**Submission**			
DESTINATION	***Full Execution***	***Partial Execution***	***Revision***	***Cancellation***
PRICEGAP	-0.484***	-0.407***	-0.535	1.430***
	(0.085)	(0.060)	(0.508)	(0.260)
INITRADE	0.278***	0.274***	0.059	0.051
	(0.039)	(0.043)	(0.037)	(0.056)
SSLIQUIDITY	-0.909***	-0.643***	-0.112***	-0.049***
	(0.041)	(0.042)	(0.011)	(0.016)
MKDPR	-0.177**	-0.091***	-0.001***	-0.001***
	(0.086)	(0.032)	(<.001)	(<.001)
OSLIQUIDITY	-0.024	0.058	0.024	0.148***
	(0.044)	(0.046)	(0.019)	(0.027)
ORDSIZE	0.131***	-0.028	-0.012	-0.239***
	(0.037)	(0.144)	(0.028)	(0.035)
CONST	-2.402***	-1.183***	-1.931***	-1.818***
	(0.042)	(0.123)	(0.237)	(0.318)
UNOBHET	-0.198***	-0.113**	-0.233***	-0.097
	(0.049)	(0.053)	(0.058)	(0.075)

Panel B

ORIGIN	**Revision**				**Partial Execution**			
DESTINATION	***Full Execution***	***Partial Execution***	***Revision***	***Cancellation***	***Full Execution***	***Partial Execution***	***Revision***	***Cancellation***
PRICEGAP	-0.438***	-0.081	-0.412**	-0.432	0.066**	-0.051*	-0.133	0.372**
	(0.106)	(0.104)	(0.193)	(0.348)	(0.033)	(0.029)	(0.091)	(0.176)
INITRADE	0.404***	0.148	0.032	0.055	0.089***	0.134***	0.411***	-0.293
	(0.095)	(0.100)	(0.064)	(0.137)	(0.033)	(0.027)	(0.083)	(0.289)
SSLIQUIDITY	-0.594***	-0.247**	-0.409***	-0.151	0.043	-0.028	-0.529***	-0.163
	(0.098)	(0.096)	(0.073)	(0.145)	(0.036)	(0.032)	(0.080)	(0.149)
MKDPR	-0.144*	0.201***	-0.185	-0.322	-0.112***	-0.107***	-0.159*	0.514*
	(0.085)	(0.077)	(0.186)	(0.314)	(0.030)	(0.025)	(0.090)	(0.290)
OSLIQUIDITY	-0.112	0.039	-0.201***	-0.278*	0.265***	0.138	0.861***	-0.054
	(0.088)	(0.084)	(0.075)	(0.157)	(0.095)	(0.087)	(0.249)	(0.453)
ORDSIZE	0.366	-0.675***	0.143**	-0.019	0.012	0.030	-0.158	0.339
	(0.253)	(0.260)	(0.068)	(0.155)	(0.089)	(0.083)	(0.233)	(0.420)
PREVDUR	-0.004***	-0.005***	-0.003***	-0.001	-0.003***	-0.004***	-0.003**	-0.010***
	(0.001)	(0.001)	(0.001)	(0.002)	(0.001)	(<.001)	(0.002)	(0.003)
CONST	-1.328***	-0.882***	-2.184***	-2.952***	-0.522***	-0.764***	-0.748***	-1.502***
	(0.336)	(0.196)	(0.091)	(0.184)	(0.038)	(0.033)	(0.091)	(0.169)
UNOBHET	-0.169	-0.151	-0.195**	-0.342	0.045	-0.172***	0.431***	0.359***
	(0.105)	(0.095)	(0.092)	(0.220)	(0.034)	(0.034)	(0.060)	(0.117)

3.4.4. Multiple-Spell Survival Analysis of Dynamic Limit Order Placement Strategies Following the Two Major Structural Changes of the ASX

In October 2006, ASX replaced SEATS by the Integrated Trading System (ITS) and in November 2010, ITS was again replaced by ASX Trade. The structural changes have reduced the market latency significantly, providing an environment for high-frequency trading in the marketplace. This study also examines dynamic limit order placement strategies in the stock market following these two major technological improvements, using survival analysis with multiple-spell duration as the research tool. The results for the sample of the ITS period (August 2007) are reported in *Table 3.13* and *Table 3.14* for buy and sell limit orders, respectively. The results for the sample of the ASX Trade period (August 2011) are presented in *Table 3.15* and *Table 3.16* for buy and sell limit orders, respectively. The coefficient estimates are reported for each variable and the standard errors are included in the parentheses.

Table 3.13: Multiple-Spell Duration Analysis of Buy Limit Orders in the ITS Period (August 2007 Sample)

This table presents the results for the multiple-spell duration survival analysis of buy limit orders in the period that the ASX operated the Integrated Trading System (August 2007 sample). The table describes the study of limit order dynamics as a sequence of multiple limit order events. The estimation model used in this survival analysis is the Proportional Hazard model under the exponential distribution for limit order times. Definitions of the explanatory variables are given in the text. Panel A reports the results for limit order executions (including full and partial), limit order revisions and limit order cancellations that followed a limit order submission. Panel B presents the results for the limit order events that followed a limit order revision and Panel C reports the results for the limit order events that followed a limit order partial execution. The coefficient estimates are presented for each of the variable and the standard errors are reported in the parentheses. ***, **, * denote statistical significance at the 1, 5 and 10 percent level, respectively.

Panel A

ORIGIN	**Submission**			
DESTINATION	***Full Execution***	***Partial Execution***	***Revision***	***Cancellation***
PRICEGAP	0.217***	0.215***	0.068***	0.125***
	(0.004)	(0.008)	(0.004)	(0.005)
INITRADE	-0.145***	-0.112***	-0.030***	-0.083***
	(0.004)	(0.007)	(0.004)	(0.004)
SSLIQUIDITY	-0.704***	-0.597***	-0.592***	-1.359***
	(0.005)	(0.012)	(0.012)	(0.012)
MKDPR	-0.595***	-0.815***	1.070***	1.109***
	(0.009)	(0.019)	(0.016)	(0.025)
OSLIQUIDITY	0.075***	-0.065***	-0.051***	-0.231***
	(0.004)	(0.009)	(0.004)	(0.005)
ORDSIZE	-0.010**	0.006	-0.591***	0.390***
	(0.004)	(0.010)	(0.011)	(0.012)
CONST	0.626***	1.026***	0.215***	1.111***
	(0.004)	(0.009)	(0.004)	(0.005)
UNOBHET	0.251***	0.448***	0.051***	0.471***
	(0.004)	(0.006)	(0.004)	(0.003)

Panel B

ORIGIN	**Revision**				**Partial Execution**			
DESTINATION	***Full Execution***	***Partial Execution***	***Revision***	***Cancellation***	***Full Execution***	***Partial Execution***	***Revision***	***Cancellation***
PRICEGAP	0.130***	0.207***	0.033***	0.005	0.024***	0.077***	0.081***	0.107***
	(0.007)	(0.022)	(0.003)	(0.012)	(0.007)	(0.008)	(0.014)	(0.025)
INITRADE	-0.060***	-0.057***	-0.015***	-0.004	-0.083***	-0.191***	-0.116***	-0.426***
	(0.005)	(0.012)	(0.002)	(0.011)	(0.008)	(0.010)	(0.014)	(0.021)
SSLIQUIDITY	-0.597***	-0.594***	-0.212***	-0.017	-0.356***	-0.583***	-0.209***	-0.743***
	(0.010)	(0.028)	(0.004)	(0.025)	(0.009)	(0.014)	(0.015)	(0.022)
MKDPR	-0.601***	-0.524***	0.076***	1.044***	-0.044***	-0.005	-0.004	0.020
	(0.012)	(0.019)	(0.005)	(0.028)	(0.008)	(0.009)	(0.013)	(0.018)
OSLIQUIDITY	-0.061***	-0.109***	-0.125***	0.136***	0.043***	0.053***	0.047***	0.206***
	(0.005)	(0.013)	(0.003)	(0.012)	(0.007)	(0.010)	(0.014)	(0.021)
ORDSIZE	0.116***	-0.074***	0.109***	-1.130***	0.128***	-0.106***	0.015	0.173***
	(0.007)	(0.024)	(0.004)	(0.027)	(0.008)	(0.010)	(0.014)	(0.020)
PREVDUR	-0.020***	-0.014***	-0.003***	-0.014***	-0.003***	-0.003***	-0.009***	-0.013***
	(<.001)	(<.001)	(<.001)	(<.001)	(<.001)	(<.001)	(0.001)	(0.002)
CONST	1.137***	1.497***	0.806***	1.107***	2.328***	2.740***	0.596***	2.098***
	(0.007)	(0.017)	(0.003)	(0.014)	(0.008)	(0.010)	(0.016)	(0.023)
UNOBHET	-0.169***	0.096***	-0.159***	0.425***	0.279***	0.457***	-0.139***	0.635***
	(0.007)	(0.013)	(0.003)	(0.010)	(0.006)	(0.007)	(0.017)	(0.014)

Table 3.14: Multiple-Spell Duration Analysis of Sell Limit Orders in the ITS Period (August 2007 Sample)

This table presents the results for the multiple-spell duration survival analysis of sell limit orders in the period that the ASX operated the Integrated Trading System (August 2007 sample). The table describes the study of limit order dynamics as a sequence of multiple limit order events. The estimation model used in this survival analysis is the Proportional Hazard model under the exponential distribution for limit order times. Definitions of the explanatory variables are given in the text. Panel A reports the results for limit order executions (including full and partial), limit order revisions and limit order cancellations that followed a limit order submission. Panel B presents the results for the limit order events that followed a limit order revision and Panel C reports the results for the limit order events that followed a limit order partial execution. The coefficient estimates are presented for each of the variable and the standard errors are reported in the parentheses. ***, **, * denote statistical significance at the 1, 5 and 10 percent level, respectively.

Panel A

ORIGIN	**Submission**			
DESTINATION	***Full Execution***	***Partial Execution***	***Revision***	***Cancellation***
PRICEGAP	-0.109***	-0.233***	0.033**	0.250***
	(0.011)	(0.030)	(0.016)	(0.006)
INITRADE	0.063***	0.017***	-0.002	-0.056***
	(0.004)	(0.006)	(0.004)	(0.004)
SSLIQUIDITY	-0.758***	-0.819***	-3.045***	-0.522***
	(0.005)	(0.010)	(0.039)	(0.001)
MKDPR	1.009***	0.734***	-2.962***	-0.097***
	(0.013)	(0.013)	(0.038)	(0.001)
OSLIQUIDITY	0.040***	-0.087***	-0.132***	-0.197***
	(0.004)	(0.008)	(0.005)	(0.002)
ORDSIZE	0.135***	0.249***	-0.077***	-0.023***
	(0.011)	(0.031)	(0.015)	(0.001)
CONST	0.680***	1.009***	0.480***	2.970***
	(0.004)	(0.007)	(0.005)	(0.015)
UNOBHET	0.039***	0.328***	0.157***	0.461***
	(0.004)	(0.006)	(0.004)	(0.003)

Panel B

ORIGIN	**Revision**				**Partial Execution**			
DESTINATION	***Full Execution***	***Partial Execution***	***Revision***	***Cancellation***	***Full Execution***	***Partial Execution***	***Revision***	***Cancellation***
PRICEGAP	-0.136***	-0.185***	-0.028	0.078***	-0.073***	0.029	-0.041	-0.158***
	(0.012)	(0.045)	(0.017)	(0.010)	(0.019)	(0.021)	(0.037)	(0.048)
INITRADE	-0.017***	-0.012	-0.038***	-0.049***	0.063***	0.114***	0.133***	0.287***
	(0.005)	(0.010)	(0.002)	(0.011)	(0.007)	(0.005)	(0.014)	(0.019)
SSLIQUIDITY	-0.603***	-0.700***	0.007	-0.006***	-0.243***	-0.461***	-0.273***	-0.672***
	(0.009)	(0.020)	(0.018)	(0.001)	(0.008)	(0.010)	(0.013)	(0.018)
MKDPR	0.527***	0.490***	-0.051***	-0.052***	0.050***	-0.001	-0.014	0.024
	(0.008)	(0.016)	(0.014)	(0.009)	(0.007)	(0.004)	(0.014)	(0.019)
OSLIQUIDITY	-0.038***	-0.117***	-0.150***	-0.019***	0.043***	0.058***	0.070***	0.260***
	(0.006)	(0.011)	(0.003)	(0.005)	(0.007)	(0.007)	(0.013)	(0.018)
ORDSIZE	0.169***	0.182***	-0.039***	-0.005***	0.096***	-0.024	0.060	0.246***
	(0.013)	(0.049)	(0.015)	(0.001)	(0.019)	(0.021)	(0.038)	(0.050)
PREVDUR	-0.015***	-0.012***	-0.003***	-0.018***	-0.004***	-0.004***	-0.008***	-0.015***
	(<.001)	(<.001)	(<.001)	(<.001)	(<.001)	(<.001)	(0.001)	(0.002)
CONST	1.064***	1.452***	0.889***	1.668***	2.351***	2.500***	0.865***	2.235***
	(0.007)	(0.014)	(0.003)	(0.033)	(0.007)	(0.007)	(0.015)	(0.019)
UNOBHET	-0.283***	-0.003	-0.112***	0.428***	0.155***	0.266***	0.003	0.603***
	(0.007)	(0.012)	(0.003)	(0.009)	(0.006)	(0.005)	(0.014)	(0.012)

The sign of the *PRICEGAP* coefficient estimates is perhaps one of the most noticeable differences in the results of the two periods following the major structural changes as compared to the initial period of year 2000. Specifically, most of the *PRICEGAP* estimates are positive and significant in both samples of ITS and ASX Trade periods. This positive effect is especially more evident in the sample of buy limit orders. The *PRICEGAP* estimate is, however, mostly negative in the year 2000 period. It could be argued that this positive effect in these two recent periods shows a higher trading intensity due to improvements in market latency. A higher value of *PRICEGAP* indicates the initial position of a limit order as being more defensive (a lower limit price for a buy order and a higher limit price for a sell order). A positive relationship with the hazard rates, especially for spells that transit to revision and cancellation events, seems to suggest that trading activities in these periods are very active and intensive. Whenever the order placement starts from a defensive position, there is a higher probability that the limit order will be revised or cancelled. The market environment with improved technology is characterised by a significant number of high-frequency trading (HFT) and algorithmic plays. As a result, HFT could cause the stock market to become very volatile at times where new opportunities for defensive traders are presented, or their opportunity costs are reduced, or their positions are adversely affected. Consequently, traders respond to these market conditions by intensifying their revision and cancellation activities.

It is also interesting to observe that the coefficient estimates of the unobserved heterogeneity variable, *UNOBHET*, show some distinctions in the two recent periods as opposed to the initial period of study. Even though the results are generally consistent for buy and sell limit orders that are originated from order submission and partial execution, they are not consistent with prior sample for orders departing from limit order revisions. Specifically, ITS period has seen positive and significant coefficient estimates of *UNOBHET* in revision-to-cancellation spells; and ASX Trade period has witnessed significantly positive estimates of *UNOBHET* in both revision-to-cancellation and revision-to-revision spells. The improvement in latency has definitely increased the responsiveness of dynamic order placement strategies across most types of limit order transitions. The coefficient estimates of *PREVDUR*, the duration dependence variable, show consistent results with the earlier period. They are also significantly negative across limit order events that are originated from both revisions and partial executions. Negative duration dependence is a common finding in many studies on survival analysis with multiple-spell duration, especially in the literature of labour economics. Booth et al. (2002) and De Graaf-Zijl et al. (2011), among others, examine past durations and present probability of transitions from a temporary contract, and draw a conclusion with a significantly negative relationship. As evidenced, even after the structural changes, the limit order spells still experience a similar pattern where the probability of completing a spell is lower if the limit order's previous duration is longer.

Table 3.15: Multiple-Spell Duration Analysis of Buy Limit Orders in the ASX Trade Period (August 2011 Sample)

This table presents the results for the multiple-spell duration survival analysis of buy limit orders in the period that the ASX Trade was in operation (August 2011 sample). The table describes the study of limit order dynamics as a sequence of multiple limit order events. The estimation model used in this survival analysis is the Proportional Hazard model under the exponential distribution for limit order times. Definitions of the explanatory variables are given in the text. Panel A reports the results for limit order executions (including full and partial), limit order revisions and limit order cancellations that followed a limit order submission. Panel B presents the results for the limit order events that followed a limit order revision and Panel C reports the results for the limit order events that followed a limit order partial execution. The coefficient estimates are presented for each of the variable and the standard errors are reported in the parentheses. ***, **, * denote statistical significance at the 1, 5 and 10 percent level, respectively.

Panel A

ORIGIN	**Submission**			
DESTINATION	***Full Execution***	***Partial Execution***	***Revision***	***Cancellation***
PRICEGAP	-0.030***	0.214***	0.100***	0.025***
	(0.010)	(0.007)	(0.003)	(0.002)
INITRADE	0.130***	0.012*	-0.066***	-0.054***
	(0.010)	(0.007)	(0.003)	(0.002)
SSLIQUIDITY	0.248***	-1.390***	-0.516***	-0.238***
	(0.014)	(0.008)	(0.004)	(0.002)
MKDPR	-0.604***	-0.806***	0.005	0.161***
	(0.019)	(0.013)	(0.008)	(0.003)
OSLIQUIDITY	-0.022**	0.036***	-0.378***	-0.311***
	(0.011)	(0.007)	(0.004)	(0.002)
ORDSIZE	0.414***	0.730***	0.448***	-0.140***
	(0.012)	(0.008)	(0.004)	(0.002)
CONST	8.024***	3.316***	2.316***	1.762***
	(0.012)	(0.009)	(0.004)	(0.002)
UNOBHET	0.133***	0.522***	0.439***	0.347***
	(0.010)	(0.006)	(0.003)	(0.002)

Panel B

ORIGIN	**Revision**				**Partial Execution**			
DESTINATION	***Full Execution***	***Partial Execution***	***Revision***	***Cancellation***	***Full Execution***	***Partial Execution***	***Revision***	***Cancellation***
PRICEGAP	0.252***	0.222***	0.079***	0.001	0.020	0.132***	0.113***	0.090***
	(0.015)	(0.013)	(0.002)	(0.005)	(0.023)	(0.015)	(0.030)	(0.022)
INITRADE	-0.028**	0.059***	-0.058***	-0.128***	0.082***	-0.161***	-0.364***	-0.212***
	(0.012)	(0.011)	(0.003)	(0.005)	(0.029)	(0.022)	(0.024)	(0.026)
SSLIQUIDITY	-2.916***	-1.503***	-0.525***	-0.044***	-0.328***	-0.888***	-1.157***	-0.866***
	(0.024)	(0.020)	(0.003)	(0.007)	(0.044)	(0.026)	(0.047)	(0.032)
MKDPR	-0.578***	-0.695***	-0.157***	-0.139***	-0.557***	-0.340***	-0.107***	-0.150***
	(0.015)	(0.016)	(0.005)	(0.006)	(0.026)	(0.030)	(0.040)	(0.023)
OSLIQUIDITY	0.338***	-0.047***	-0.446***	-0.304***	-0.017	0.025	-0.064***	-0.222***
	(0.014)	(0.012)	(0.003)	(0.006)	(0.027)	(0.017)	(0.023)	(0.024)
ORDSIZE	0.783***	0.991***	0.725***	0.312***	0.187***	-0.038**	1.488***	1.329***
	(0.017)	(0.013)	(0.003)	(0.007)	(0.034)	(0.018)	(0.066)	(0.035)
PREVDUR	-0.026***	-0.021***	-0.016***	-0.035***	-0.016***	-0.004***	0.007***	-0.022***
	(0.001)	(0.001)	(<.001)	(<.001)	(0.001)	(0.001)	(0.002)	(0.002)
CONST	5.889***	3.549***	5.002***	3.571***	9.230***	6.914***	6.595***	6.914***
	(0.022)	(0.017)	(0.004)	(0.007)	(0.029)	(0.020)	(0.027)	(0.025)
UNOBHET	0.712***	0.468***	0.988***	0.705***	1.216***	1.247***	1.386***	1.488***
	(0.008)	(0.010)	(0.002)	(0.004)	(0.011)	(0.007)	(0.009)	(0.008)

Table 3.16: Multiple-Spell Duration Analysis of Sell Limit Orders in the ASX Trade Period (August 2011 Sample)

This table presents the results for the multiple-spell duration survival analysis of sell limit orders in the period that the ASX Trade was in operation (August 2011 sample). The table describes the study of limit order dynamics as a sequence of multiple limit order events. The estimation model used in this survival analysis is the Proportional Hazard model under the exponential distribution for limit order times. Definitions of the explanatory variables are given in the text. Panel A reports the results for limit order executions (including full and partial), limit order revisions and limit order cancellations that followed a limit order submission. Panel B presents the results for the limit order events that followed a limit order revision and Panel C reports the results for the limit order events that followed a limit order partial execution. The coefficient estimates are presented for each of the variable and the standard errors are reported in the parentheses. ***, **, * denote statistical significance at the 1, 5 and 10 percent level, respectively.

Panel A

ORIGIN	**Submission**			
DESTINATION	***Full Execution***	***Partial Execution***	***Revision***	***Cancellation***
PRICEGAP	0.080***	-0.025***	-0.563***	0.413***
	(0.017)	(0.007)	(0.014)	(0.009)
INITRADE	0.058***	0.044***	0.027***	0.015***
	(0.006)	(0.003)	(0.003)	(0.002)
SSLIQUIDITY	-1.982***	-1.289***	-2.350***	-0.730***
	(0.006)	(0.005)	(0.022)	(0.005)
MKDPR	2.030***	1.203***	-2.466***	-0.437***
	(0.057)	(0.022)	(0.022)	(0.006)
OSLIQUIDITY	0.080***	-0.007	-0.398***	-0.289***
	(0.006)	(0.004)	(0.003)	(0.002)
ORDSIZE	-0.034**	0.042***	0.398***	-0.414***
	(0.017)	(0.008)	(0.010)	(0.008)
CONST	3.861***	1.539***	2.239***	1.892***
	(0.008)	(0.004)	(0.004)	(0.003)
UNOBHET	0.747***	0.166***	0.361***	0.423***
	(0.004)	(0.004)	(0.003)	(0.002)

Panel B

ORIGIN	**Revision**				**Partial Execution**			
DESTINATION	***Full Execution***	***Partial Execution***	***Revision***	***Cancellation***	***Full Execution***	***Partial Execution***	***Revision***	***Cancellation***
PRICEGAP	-0.239***	-0.089***	-1.726***	-0.196***	-0.018	-0.601***	-0.604***	-0.921***
	(0.034)	(0.009)	(0.014)	(0.009)	(0.019)	(0.025)	(0.062)	(0.071)
INITRADE	-0.028***	0.019***	0.006**	0.043***	0.337***	0.871***	0.404***	0.247***
	(0.011)	(0.005)	(0.003)	(0.005)	(0.009)	(0.015)	(0.022)	(0.024)
SSLIQUIDITY	-1.491***	-0.977***	-0.292***	-0.090***	-1.230***	-0.421***	-0.556***	-0.612***
	(0.013)	(0.007)	(0.005)	(0.006)	(0.012)	(0.006)	(0.025)	(0.029)
MKDPR	2.791***	1.874***	-0.560***	-0.819***	0.003	0.004	0.023*	0.092***
	(0.107)	(0.055)	(0.010)	(0.025)	(0.015)	(0.007)	(0.013)	(0.017)
OSLIQUIDITY	0.330***	-0.033***	-0.114***	-0.273***	0.009	0.211***	-0.138***	-0.066***
	(0.011)	(0.006)	(0.003)	(0.006)	(0.010)	(0.006)	(0.022)	(0.023)
ORDSIZE	0.378***	0.107***	1.909***	0.184***	0.010	0.086***	0.680***	1.178***
	(0.035)	(0.009)	(0.015)	(0.010)	(0.018)	(0.003)	(0.068)	(0.094)
PREVDUR	-0.013***	-0.023***	-0.014***	-0.034***	-0.001***	-0.006***	0.007***	-0.021***
	(0.001)	(0.001)	(<.001)	(<.001)	(<.001)	(0.001)	(0.002)	(0.002)
CONST	3.885***	1.948***	5.257***	3.426***	5.763***	6.877***	6.540***	7.097***
	(0.014)	(0.006)	(0.004)	(0.006)	(0.011)	(0.052)	(0.026)	(0.024)
UNOBHET	0.716***	-0.063***	1.059***	0.640***	1.189***	1.329***	1.380***	1.500***
	(0.007)	(0.006)	(0.001)	(0.004)	(0.004)	(0.005)	(0.009)	(0.008)

The above results are indeed consistent with the view suggested by Fong and Liu (2010) that non-execution cost is a major source of risk in limit order placements. When it is not easy to buy or sell in the market place (for instance, in an illiquid market), traders are likely to adjust their orders faster to make sure that their orders can be filled. Alternatively, traders can cancel the orders to reduce any opportunity cost. This result is also in harmony with the view of Biais et al. (1995) that traders' order placement strategies tend to vary with market conditions[6]. Specifically, when the spreads are wide, there would be more limit orders and when the spreads are narrow, there would be more market orders.

For completeness, survival analysis with multiple-spell duration model has also been conducted for the two samples of large-cap and small-cap stocks in both periods following ASX's structural changes. Tables reporting the results are presented in the Appendix at the end of this thesis. For the ITS period (August 2007 sample), *Table A.1* and *Table A.3* present the estimation results for buy limit orders, whereas *Table A.2* and *Table A.4* report the estimation results for sell limit orders for large and small stocks, respectively. Similarly, for the ASX Trade period (August 2011 sample), *Table A.5* and *Table A.7* show the estimation results for buy limit orders, whereas *Table A.6* and *Table A.8* report the estimation results for sell limit orders for large and small stocks, respectively.

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[6] The findings of Biais et al. (1995) come from a study of the order flow on the Paris Bourse.

3.5. Conclusion

This chapter employs survival analysis with both single-spell and multiple-spell duration in order to study dynamic limit order placement strategies and their determinants. The results consistently suggest that the placement of a limit order is determined by the order characteristics as well as the conditions of the stock market when the order is submitted. In particular, a limit order with a larger size is monitored more closely by traders, therefore it gains better execution rate than a smaller-size order. However, the larger-size limit orders are also revised and cancelled more rapidly under unfavourable market conditions. The time-to-an-order-event tends to be shorter when there is a smaller gap between limit order price and the prevailing mid-quote. In addition, market liquidity is found to be significantly and negatively related to limit order duration, especially for revision and cancellation activities in dynamic order placement strategies. This result is as expected because when there are more activities in the market and there is a higher level of market liquidity, traders are likely to move quicker in an attempt to capture the newly presented opportunities in the marketplace. Specifically, the time-to-an-order-event tends to be shorter when opposite-side liquidity increases and when same-side liquidity decreases. A sell (buy) limit order has a better chance to be executed faster if the prior transaction is a buyer (seller) initiated trade. This research also finds that traders revise buy limit orders quicker and more aggressively than sell limit orders, particularly for the initial sample period in year 2000. Spells ending with limit order cancellation have the shortest duration in comparison with spells transiting from submission to execution or from submission to revision, for both small and large stocks, across both samples of buy and sell limit orders.

This thesis is probably the first to employ a multiple-spell duration model to study dynamic limit order placement strategies. By allowing for duration dependence and addressing the unobserved heterogeneity, a multiple-spell duration model of survival analysis is, arguably, a more appropriate econometric tool which can be utilised to address the dynamic of limit order placement strategies. This is because order placement strategies are constructed from series of order events rather than single, independent events. The empirical results indicate that a number of factors determine the hazard rates of limit order event transitions. The factors include limit order size, limit price, market liquidity, previous duration of the limit order spell, as well as other unobserved factors. For example, the probability of a limit order revision or cancellation is higher when there is a higher level of opposite-side liquidity. This chapter also extends the initial study by examining the dynamic limit order placement strategies following the two major structural changes in the ASX. The evidence seems to suggest that a more volatile market with a larger involvement of high-frequency trading activities may contribute to a higher hazard rate of transitions to limit order revision and cancellation.

CHAPTER 4

DYNAMIC LIMIT ORDER PLACEMENT ACTIVITIES AND THEIR EFFECTS ON STOCK MARKET QUALITY

4.1. Introduction

The previous chapter has shown that dynamic order placement strategies play a major role in financial markets, especially in the past decade. They have facilitated trading activities of large institutional traders as well as individual traders, especially through algorithmic/high-frequency trading in the recent periods. It has been observed that order placement strategies, especially with trading algorithms, enable traders to be more active in managing their orders to buy or sell stocks. However, the efficiency of these activities and the extent to which they affect the stock market quality are still a debatable issue. 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 and Hasbrouck, 1996; Parlour, 1998; Ahn et al., 2001); or order submission strategies where traders choose among market orders, limit orders, reserve (partially undisclosed) orders, and hidden (totally invisible) orders (see Buti and Rindi, 2011; Bacidore et al., 2003). Other researchers argue that transaction costs act as a motive for order placement strategies (Cohen et al., 1981). 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.

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 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 and Saar, 2013). This research aims to contribute to the current literature by examining order revision and cancellation of limit orders as parts of a dynamic strategy. Furthermore, this study utilises a more reliable approach to construct a full limit order life with order events that are non-arbitrarily linked to each other.

Another major contribution of this thesis chapter is studying the effects of dynamic limit order placement activities in a unique context. This chapter 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. The chapter shows that such activities conducted by traders have a positive impact on the stock market quality in the earlier period (year 2000). Specifically, they improve the level of liquidity and reduce the short-term volatility in the stock market. However, this positive impact is not observed in the periods following the structural changes of the Australian Securities Exchange. In particular, an increase in limit order placement activities, including revising and cancelling the submitted limit orders, is harmful for the quality of the stock market by heightening short-term volatility, widening the spreads and reducing the depth of the limit order book. So the effects in the recent periods following the structural changes are opposite to the earlier period prior to the changes. 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 more volatile or less liquid. Traders are, therefore, required to be more active in monitoring their submitted limit orders, especially when the market conditions alter adversely. The findings of this chapter 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 chapter'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 chapter proceeds as follows. *Section 4.2* describes the order flow data and the statistics that show order activities in the Australian Securities Exchange. *Section 4.3* explains the construction of measures for dynamic limit order activities and explanatory variables, as well as the specification of the empirical model employed in this study. *Section 4.4* presents the empirical results of the analysis and discusses the significance of the findings in the context of the current literature. Finally, *Section 4.5* concludes the chapter.

4.2. 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. Chapter 4 investigates the dynamic limit order placement activities of the 40 index stocks listed on the ASX over the three sample periods, year 2000, year 2007 and year 2011. 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. Small-capitalisation stocks are the 20 common stocks ranked 111th to 130th on the ASX200 index. Year 2000 is chosen since it was the first year that ASX200 index came into operation. The ASX had employed the fully computerised Stock Exchange Automated Trading System (SEATS) since 1987. In October 2006, the exchange introduced the Integrated Trading System (ITS) to replace SEATS. ITS is a fully-electronic trading system utilised with a purpose to provide quicker and more efficient transactions. Therefore year 2007 is chosen for this study as it was the year right after the inception of ITS. From November 2010, ASX Trade was put in place to replace ITS. ASX Trade is an ultra-low latency trading platform. 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, year 2011 is chosen for the purpose of this research since it was the year that immediately followed the introduction of ASX Trade. In each sample period, the month of August is chosen as the month of interest for the analyses as most preliminary end-of-year earning reports are released in August and more trading activities are expected in this month as a result. 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 4.1 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-capitalisation stocks (Panel A), small-capitalisation stocks (Panel B), and a combination of large and small stocks (Panel C). The statistics show the proportion of market and limit orders in the total number of order submissions, the ratios of order revision and order cancellation to limit order; 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 4.1* shows why it is important to consider both limit order revision and cancellation as part of dynamic order placement activities. In the pooled sample, there are 316,363 order submissions, where 157,795 submissions are buy orders and 158,568 are sell orders. The number of observations for market orders is 172,148 and the number for limit orders is 144,215. In this period, a total of 19% of limit orders submitted are later cancelled from the limit order book. There are also a large number of limit order revisions, with 67,349 order events.

Table 4.1: The Trading Activities of Limit Orders and Market Orders in the Australian Stock Exchange

This table reports the frequency of market and limit orders in the initial sample period of August 2000. The statistics are reported separately for large stocks (Panel A), small stocks (Panel B), and a combination of large and small stocks (Panel C). The statistics show the proportion of market and limit orders in the total number of order submissions, the ratios of revision and cancellation to limit order; and the ratios of revision and cancellation to submission. The numbers are presented individually for buy and sell orders.

Order Events	**Number of order events**			**Proportion of Submission**			**Ratio of revision & cancellation to limit order**			**Ratio of revision & cancellation to submission**		
	Total	*Buy*	*Sell*	*Total*	*Buy*	*Sell*	*Total*	*Buy*	*Sell*	*Total*	*Buy*	*Sell*
Panel A: Large-Capitalisation Stocks												
Submission	267,247	132,058	135,189									
Market order	148,167	72,788	75,379	55%	55%	56%						
Limit order	119,080	59,270	59,810	45%	45%	44%						
Revision	56,116	29,265	26,851				47%	49%	45%	21%	22%	20%
Cancellation	22,197	11,821	10,376				19%	20%	17%	8%	9%	8%

Order Events	Number of order events			Proportion of Submission			Ratio of revision & cancellation to limit order			Ratio of revision & cancellation to submission		
	Total	*Buy*	*Sell*	*Total*	*Buy*	*Sell*	*Total*	*Buy*	*Sell*	*Total*	*Buy*	*Sell*
Panel B: Small-Capitalisation Stocks												
Submission	49,116	25,737	23,379									
Market order	23,981	12,774	11,207	49%	50%	48%						
Limit order	25,135	12,963	12,172	51%	50%	52%						
Revision	11,233	5,644	5,589				45%	44%	46%	23%	22%	24%
Cancellation	4,494	2,669	1,825				18%	21%	15%	9%	10%	8%
Panel C: Large & Small Stocks												
Submission	316,363	157,795	158,568									
Market order	172,148	85,562	86,586	54%	54%	55%						
Limit order	144,215	72,233	71,982	46%	46%	45%						
Revision	67,349	34,909	32,440				47%	48%	45%	21%	22%	20%
Cancellation	26,691	14,490	12,201				19%	20%	17%	8%	9%	8%

4.3. Variable Constructions and Empirical Model Specification

4.3.1. Measure of the Dynamic Limit Order Placement Activities (DLOPA)

In this chapter, the dynamic activities of placing buy and sell limit orders of large and small stocks in the market are examined for the sample periods under study. Market participants can execute their stock purchases and sales by submitting both market and limit orders. This analysis will focus on the events of limit orders and its dynamic activities. The purpose of this study is to examine a series of submission, revision, execution and cancellation events of a stock and its contribution to 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 then has the options 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 *RunInProcess* measure from the 'strategic runs'. This chapter utilises a similar methodology to the one used in Hasbrouck and Saar (2013) to construct a dynamic limit order placement activity (*DLOPA*) variable to explore the effects of order placement activities on the stock market quality. *DLOPA* is computed as the time-weighted average of the number of series of limit order events that the stock experiences in a certain time interval of study. The time interval chosen is 10 minutes, which is a reasonable time frame for the purpose of examining *DLOPA*[7]. If there is a greater intensity of the dynamic activities that occur in a stock, the value of *DLOPA* will be

[7] This is also consistent with Hasbrouck and Saar (2013) who chose 10 minutes as the interval for their measure of the variable of interest, *RunInProcess*.

higher, 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 relationship with the stock market environment where the orders are submitted.

4.3.2. 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 relationship 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 time interval (*Equation 4.1*). A lower (higher) value of *Volatility* means that the market is less (more) volatile and therefore the market experiences a higher (lower) quality.

$$Volatility_{i,t} = MaxMQ_{i,t} - MinMQ_{i,t} \tag{4.1}$$

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 time interval (*Equation 4.2*). A lower (higher) value of *QuoSprd* means that the market is more (less) liquid and hence a higher (lower) quality market.

$$QuoSprd_{i} = \sum_{j=1}^{n} tw_{j}(QuoAsk_{i,j} - QuoBid_{i,j}) \tag{4.2}$$

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 time interval (*Equation 4.3*). The effective spread of a trade is defined as two times the absolute value of the difference between the transaction price and the prevailing mid-quote. A lower (higher) value of *EffSprd* means that the market is more (less) liquid and thus the market experiences a higher (lower) quality.

$$EffSprd_i = 2 \times \sum_{j=1}^{n} dvw_j \left| TP_{i,j} - MQ_{i,j} \right| \tag{4.3}$$

Finally, the fourth variable is *LOBDepth* which measures the depth of the limit order book. This variable is another measure for market liquidity and it is computed as the time-weighted average of the number of shares of a stock in the limit order book in each time interval (*Equation 4.4*). A higher (lower) value of *LOBDepth* means that the market is more (less) liquid and hence a higher (lower) quality market.

$$LOBDepth_i = \sum_{j=1}^{n} tw_j (LOBAsk_{i,j} + LOBBid_{i,j}) \tag{4.4}$$

Table 4.2 presents a summary statistics of the variables employed in this study in the initial period (August 2000) and *Table 4.3* provides a descriptive statistics for the explanatory variables constructed in the periods following the structural changes of the ASX (August 2007 and August 2011).

Table 4.2: Summary Statistics of Model Variables in the Initial Sample Period

This table presents the summary statistics for the variables used in the empirical model to study the relationship between dynamic limit order placement activities and the stock market quality in the initial period (August 2000). 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-minute 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-minute 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-minute 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-minute 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-minute interval.

	DLOPA	*VOLATILITY ($)*	*QUOSPRD ($)*	*EFFSPRD ($)*	*LOBDEPTH (1,000's)*
Mean	27.8146	0.0279	0.0264	0.0234	1,333.75
Standard Deviation	31.8597	0.0765	0.0293	0.0272	2,907.52
Minimum	0.0017	0.0000	0.0100	0.0000	18.96
Maximum	556.0883	1.9750	0.4381	0.4776	44,268.51
Number of Observations	32,557	32,557	32,557	32,557	32,557

Table 4.3: Summary Statistics of Model Variables in the Sample Periods with Reduced Latency

This table presents the summary statistics for the variables used in the empirical model to study the relationship between dynamic limit order placement activities and the stock market quality in the two periods 2007 and 2011. 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-minute 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-minute 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-minute 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-minute 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-minute interval.

Panel A: Sample 2007

	DLOPA	*VOLATILITY ($)*	*QUOSPRD ($)*	*EFFSPRD ($)*	*LOBDEPTH (1,000's)*
Mean	220.35	2.2118	0.3301	1.0953	850.91
Standard Deviation	233.58	8.3629	1.9669	5.1333	2,072.09
Minimum	1.00	0.0000	0.0001	0.0000	7.42
Maximum	2,053.29	358.6395	75.9630	90.0032	22,794.24
Number of Observations	32,143	32,143	32,143	32,143	32,143

Panel B: Sample 2011

	DLOPA	*VOLATILITY ($)*	*QUOSPRD ($)*	*EFFSPRD ($)*	*LOBDEPTH (1,000's)*
Mean	475.74	0.9576	0.1463	0.3703	2,896.24
Standard Deviation	348.46	4.5707	1.0904	1.9460	9,989.47
Minimum	6.40	0.0000	0.0001	0.0000	23.50
Maximum	2,570.53	80.0542	64.7992	53.6933	69,356.67
Number of Observations	32,013	32,013	32,013	32,013	32,013

4.3.3. Two-Equation Simultaneous Equation Model

This chapter employs a two-step approach to examine how limit order placement activities influence the quality of the stock market, especially in the periods following the two structural changes which significantly reduced the market latency of the ASX. The first step is to study the effects that dynamic limit order placement activities have on the stock market quality in the early period before the structural changes (year 2000 in this data sample). The second step is to investigate the two periods which immediately followed the two structural changes in 2006 and 2010. The year after ASX migrated its platform from SEATS to ITS (year 2007) and the year after the launch of ASX Trade (year 2011) are examined individually. This second step is useful in examining the importance and effectiveness of the structural changes, as well as inspecting how technological improvements have altered the way dynamic limit order placement activities affect the traditional stock market quality.

The empirical research methodology of this chapter involves dividing a trading day into smaller time intervals to investigate more closely the dynamic limit order placement activities which occur in the stocks during the day. For this purpose, a six-hour trading day is divided into 36 ten-minute intervals. The measures and variables are, thus, calculated for the consecutive ten-minute intervals accordingly. It is worth noting that even though a ten-minute window is reasonably short and suitable to use for examining market quality in detail, it is sufficiently long to cause the issue of simultaneity. The interest of this chapter is to study how dynamic limit order placement activities influence market quality. However, it is also possible that the existing quality of the market environment either motivates or discourages limit order placement activities.

Given the potential simultaneity issue[8], a simultaneous equation model is chosen as the empirical model for examining the relationship of limit order placement activities and the market quality. The two endogenous variables of interest are $DLOPA_{i,t}$ (the time-weighted average measure of limit order activities that a stock experiences in a specific ten-minute interval) and $MktQuality_{i,t}$ (market quality measures, namely *Volatility*, *QuoSprd*, *EffSprd*, and *LOBDepth*, computed for each ten-minute interval). Similar to the method introduced by Hasbrouck and Saar (2013), this study generates an instrument for the $DLOPA_{i,t}$ variable 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. Lagged variables are also employed as instruments for market quality measures.

The two instrumental variables for market quality and dynamic limit order placement activities in the empirical model are named *MktQualIns* and *DLOPAIns*, respectively. The simultaneous equation model is, therefore, expressed as the followings:

$$MktQuality_{i,t} = \beta_{DLOPA} \times DLOPA_{i,t} + \beta_{MktQualIns} \times MktQualIns_{i,t} + e_{mi,t} \qquad \text{(Eq. 1)}$$

$$DLOPA_{i,t} = \beta_{MktQuality} \times MktQuality_{i,t} + \beta_{DLOPAIns} \times DLOPAIns_{i,t} + e_{di,t} \qquad \text{(Eq. 2)}$$

Finally, the model of two simultaneous equations is estimated separately for each of the market quality measures (short-term volatility, quoted spread, effective spread and limit order book depth) using Two-Stage-Least-Squares (2SLS) as the estimation method. This methodology allows the endogenous variables $DLOPA_{i,t}$ in the first equation (*Eq. 1*) to be replaced by the fitted values of the regression of $DLOPA_{i,t}$ on

[8] This issue is also acknowledged in Hasbrouck and Saar (2013) and they suggest the use of a simultaneous equation model as a remedy for simultaneity.

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. In a similar way, the 2SLS method replaces *MktQuality*$_{i,t}$ in the second equation (*Eq. 2*) with the fitted values of the regression of *MktQuality*$_{i,t}$ on the instrumental variables (*MktQualIns*$_{i,t}$). The estimations are conducted for the pooled sample of year 2000, for the sample of large-cap stocks, for the sample of small-cap stocks, as well as for each individual stock (stock-by-stock analysis). The similar analyses are also carried out in the second step separately for each of the two periods of year 2007 and year 2011. In each period, the model is estimated for the full sample, for the sample of large capitalisation stocks, as well as for the sample of small capitalisation stocks.

4.4. Empirical Results

4.4.1. Market Impacts in the Early Period

Table 4.4 presents the estimation results for the empirical model when examining the pooled sample of the initial period under study (August 2000). The coefficient estimates are reported for each variable, together with their levels of significance. The standard errors are also included in the parentheses. In *Eq. 1*, the estimates of the coefficient β_{DLOPA} 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*). It is evident in *Table 4.4* that an increase in dynamic limit order placement activities results in an improvement in the stock market quality. This is observed from the significantly negative coefficient estimates of β_{DLOPA} where volatility, quoted spread and effective spread are used as market quality measures. This result suggests that as traders increase their activities in managing the submitted limit orders, they influence the surrounding market environment and consequently lower the stock's volatility, narrower the trading spreads, hence improve the liquidity level for the stock. Where the depth of the limit order book is used as a measure of market quality, the coefficient estimate of β_{DLOPA} is positive. This suggests that a higher level of dynamic order activities also increases the market liquidity by supplying more limit orders and enhancing the depth of the limit order book. This effect on the limit-order-book depth is, however, not statistically significant in the pooled sample of this period. The results of *Eq. 1* share a consistent view with a number of studies in the literature regarding the efficiency of dynamic order trading activities (see, for example, Brogaard et al., 2014; Hasbrouck and Saar, 2013).

Table 4.4: Effects of Dynamic Limit Order Placement Activities on Market Quality in the Initial Period (August 2000)

This table presents the empirical results for the study of dynamic limit order placement activities and how they affect stock market quality using the initial sample period (August 2000). *Volatility* measures the short term volatility in the market. *QuoSprd* measures the level of liquidity, calculated as time-weighted average of the quoted bid/ask spreads. *EffSprd* also measures the level of liquidity, but 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-minute interval. The empirical model employs two instrumental variables for market quality and dynamic limit order placement activities, namely, *MktQualIns* and *DLOPAIns* respectively. The coefficient estimates are presented for each of the variable and the standard errors are reported in the parentheses. ***, **, * denote statistical significance at the 1, 5 and 10 percent level respectively. The following model of two simultaneous equations is estimated separately for each of the market quality measures, using Two-Stage-Least-Squares as the estimation method:

$$MktQuality_{i,t} = \beta_{DLOPA} \times DLOPA_{i,t} + \beta_{MktQualIns} \times MktQualIns_{i,t} + e_{mi,t} \quad \text{(Eq. 1)}$$

$$DLOPA_{i,t} = \beta_{MktQuality} \times MktQuality_{i,t} + \beta_{DLOPAIns} \times DLOPAIns_{i,t} + e_{di,t} \quad \text{(Eq. 2)}$$

	EQUATION 1				EQUATION 2			
	Volatility	QuoSprd	EffSprd	LOBDepth	DLOPA			
DLOPA	-0.1094***	-0.2723***	-0.1907***	0.0014				
	(0.0278)	(0.0269)	(0.0269)	(0.0277)				
MktQualIns	0.2121***	0.2006***	0.1771***	-0.0653***				
	(0.0070)	(0.0068)	(0.0068)	(0.0070)				
DLOPAIns					0.2213***	0.2596***	0.2454***	0.2036***
					(0.0067)	(0.0093)	(0.0094)	(0.0156)
Volatility					0.8273***			
					(0.0339)			
QuoSprd						1.0268***		
						(0.0551)		
EffSprd							1.0991***	
							(0.0610)	
LOBDepth								-2.4741***
								(0.2399)

The results in *Eq. 2* of the simultaneous equation model show an interesting insight into the interactions between limit order activities dynamically managed by traders and the market environment where the limit orders are submitted. The estimates of the coefficient of interest, $\beta_{MktQuality}$, are positive and statistically significant when short term volatility, quoted spread and effective spread are used as market quality measures. This result implies that a low quality market environment tends to encourage higher level of limit order activities. In particular, traders tend to be more motivated to revise or cancel limit orders when the market condition becomes more volatile, liquidity level drops as spreads are widened. The coefficient estimate of $\beta_{MktQuality}$ is significantly negative when the depth of the limit order book is used as a measure of market quality. This negative relationship confirms that when the market turns illiquid with a reduced depth in the limit order book, traders respond by increasing their activities and become more active in revising or cancelling their submitted orders. The results are indeed consistent with the findings of previous research in this particular area. Ranaldo (2004), for instance, studies the order aggressiveness in limit order book markets and finds that traders become more aggressive when the own (opposite) side book is thicker (thinner), the spread wider, and the temporary volatility increases. Similarly, Menkhoff et al. (2010) investigate the limit-order submission activities under asymmetric information and report that informed traders are highly sensitive to spreads, volatility, momentum and depth.

The empirical results indicate that dynamic limit order activities respond to stock market conditions. Furthermore, as these activities intensify, they in turn affect the quality of the market. Indeed, traders submit their limit orders conditioning on the original market states at the point of limit order submission. However, 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 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.

4.4.2. Dynamic Limit Order Placement Activities of Large Stocks versus Small Stocks

To provide a closer examination of the interactions between dynamic limit order placement activities and stock market quality, the analysis is performed separately for large-cap stocks and small-cap stocks of the ASX in the initial period of study (August 2000). *Table 4.5* reports the estimation results for the empirical model using the sample of large-cap stocks while the estimation results for the sample of small-cap stocks are presented in *Table 4.6*.

Table 4.5: Effects of Dynamic Limit Order Placement Activities of Large-Cap Stocks on Market Quality in the Initial Sample Period (August 2000)

This table presents the model estimations for the study of dynamic limit order placement activities of large-cap stocks and the effects on stock market quality in the initial period (August 2000). *Volatility* measures the short term volatility in the market. *QuoSprd* measures the level of liquidity, calculated as time-weighted average of the quoted bid/ask spreads. *EffSprd* also measures the level of liquidity, but 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-minute interval. The empirical model employs two instrumental variables for market quality and dynamic limit order placement activities, namely, *MktQualIns* and *DLOPAIns* respectively. The coefficient estimates are presented for each of the variable and the standard errors are reported in the parentheses. ***, **, * denote statistical significance at the 1, 5 and 10 percent level respectively. The following model of two simultaneous equations is estimated separately for each of the market quality measures, using Two-Stage-Least-Squares as the estimation method:

$$MktQuality_{i,t} = \beta_{DLOPA} \times DLOPA_{i,t} + \beta_{MktQualIns} \times MktQualIns_{i,t} + e_{mi,t} \qquad \text{(Eq. 1)}$$

$$DLOPA_{i,t} = \beta_{MktQuality} \times MktQuality_{i,t} + \beta_{DLOPAIns} \times DLOPAIns_{i,t} + e_{di,t} \qquad \text{(Eq. 2)}$$

	EQUATION 1				EQUATION 2			
	Volatility	QuoSprd	EffSprd	LOBDepth	DLOPA			
DLOPA	-0.0378	-0.2083***	-0.1628***	0.0770***				
	(0.0232)	(0.0223)	(0.0225)	(0.0244)				
MktQualIns	0.1535***	0.2086***	0.1972***	-0.0631***				
	(0.0079)	(0.0076)	(0.0076)	(0.0083)				
DLOPAIns					0.3431***	0.3594***	0.3555***	0.3153***
					(0.0079)	(0.0089)	(0.0088)	(0.0135)
Volatility					0.3913***			
					(0.0521)			
QuoSprd						0.3016***		
						(0.0422)		
EffSprd							0.3157***	
							(0.0443)	
LOBDepth								-0.8745***
								(0.1890)

Table 4.6: Effects of Dynamic Limit Order Placement Activities of Small-Cap Stocks on Market Quality in the Initial Sample Period (August 2000)

This table presents the model estimations for the study of dynamic limit order placement activities of small-cap stocks and the effects on stock market quality in the initial period (August 2000). *Volatility* measures the short term volatility in the market. *QuoSprd* measures the level of liquidity, calculated as time-weighted average of the quoted bid/ask spreads. *EffSprd* also measures the level of liquidity, but 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-minute interval. The empirical model employs two instrumental variables for market quality and dynamic limit order placement activities, namely, *MktQualIns* and *DLOPAIns* respectively. The coefficient estimates are presented for each of the variable and the standard errors are reported in the parentheses. ***, **, * denote statistical significance at the 1, 5 and 10 percent level respectively. The following model of two simultaneous equations is estimated separately for each of the market quality measures, using Two-Stage-Least-Squares as the estimation method:

$$MktQuality_{i,t} = \beta_{DLOPA} \times DLOPA_{i,t} + \beta_{MktQualIns} \times MktQualIns_{i,t} + e_{mi,t} \quad \text{(Eq. 1)}$$

$$DLOPA_{i,t} = \beta_{MktQuality} \times MktQuality_{i,t} + \beta_{DLOPAIns} \times DLOPAIns_{i,t} + e_{di,t} \quad \text{(Eq. 2)}$$

	EQUATION 1				EQUATION 2			
	Volatility	QuoSprd	EffSprd	LOBDepth	DLOPA			
DLOPA	-0.1114**	-0.2694***	-0.1684***	-0.0373				
	(0.0471)	(0.0456)	(0.0458)	(0.0479)				
MktQualIns	0.2237***	0.1924***	0.1638***	-0.0443***				
	(0.0098)	(0.0095)	(0.0096)	(0.0100)				
DLOPAIns					0.1809***	0.2065***	0.1951***	0.1527***
					(0.0088)	(0.0117)	(0.0120)	(0.0252)
Volatility					0.6152***			
					(0.0417)			
QuoSprd						0.8170***		
						(0.0708)		
EffSprd							0.9063***	
							(0.0819)	
LOBDepth								-2.6228***
								(0.5122)

The coefficient estimates for β_{DLOPA} in *Eq. 1* are quite consistent in term of signs for the two samples of large and small stocks. They also confirm the consistent finding obtained in the pooled sample. It is worth noting that the sample of large stocks shows an even stronger result than the pooled sample with the coefficient estimate of β_{DLOPA} being positive and statistically significant when the depth of the limit order book (*LOBDepth*) is used as a market quality measure. The results certainly indicate that a higher level of order placement activities conducted by traders indeed reduces short term volatility and increases liquidity for the stocks. The estimates of the coefficient $\beta_{MktQuality}$ in *Eq. 2* also verify what have been learned from the pooled sample. They are significantly positive when volatility, quoted spread and effective spread are used as market quality measures and significantly negative when the depth of the limit order book is used. This result, again, suggests that traders respond to market conditions and adjust their level of activities accordingly. As the quality of the market place worsens, the level of dynamic limit order placement activities begins to rise.

It should also be noted about the statistical and economic significance of the coefficient estimates in the two categories of stocks. *Eq. 1* shows somewhat similar coefficient estimates for β_{DLOPA} when quoted spread and effective spread are used as market quality measures. However, when short term volatility is used, the coefficient estimate of β_{DLOPA} in the small stock sample is relatively larger in absolute magnitude and is also more statistical significant. This observation suggests that dynamic limit order placement activities have a relatively greater and more significant effect in reducing short term volatility for the small stocks than for the large stocks. These activities, however, do not have a significant impact on the depth of the limit order book for the small stocks. *Eq. 2* also reports the dominance of small stocks in term of the economic significance of the coefficient estimates for $\beta_{MktQuality}$. Indeed, the estimates obtained for the coefficient $\beta_{MktQuality}$ in the small stock sample are at least double in absolute magnitude compared to those in the large stock sample. This phenomenon can be explained by the fact that small stocks are less heavily traded than large stocks. Therefore a change in market conditions can cause a larger move in volatility and liquidity level for the small stocks. It thus requires more active responses by traders to adjust to the new market conditions. Hence a larger intensity of limit order activities is observed for the small stocks when the market becomes more turbulent. As a result, the coefficient estimates of $\beta_{MktQuality}$ in the sample of small-cap stocks are relatively more economically significant than those in the sample of large-cap stocks.

4.4.3. Robustness Checks

To check for the robustness of the results, further analyses at the stock-by-stock level are carried out to examine the interactions between dynamic limit order placement activities and the quality of the stock market. The simultaneous equation model is estimated separately for each of the individual stock in the sample under study. *Table 4.7* presents the median coefficient estimates across the stocks, their significance levels and the corresponding standard errors for each of the variable in the empirical model.

Table 4.7: Stock-by-Stock Analysis of Dynamic Limit Order Placement Activities and Market Quality

This table reports the empirical model estimations for the study of dynamic limit order placement activities and stock market quality on a stock-by-stock basis in the initial sample period (August 2000). *Volatility* measures the short term volatility in the market. *QuoSprd* measures the level of liquidity, calculated as time-weighted average of the quoted bid/ask spreads. *EffSprd* also measures the level of liquidity, but 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-minute interval. The empirical model employs two instrumental variables for market quality and dynamic limit order placement activities, namely, *MktQualIns* and *DLOPAIns* respectively. The coefficient estimates are presented for each of the variable and the standard errors are reported in the parentheses. ***, **, * denote statistical significance at the 1, 5 and 10 percent level respectively. The following model of two simultaneous equations is estimated separately for each of the market quality measures, using Two-Stage-Least-Squares as the estimation method:

$$MktQuality_{i,t} = \beta_{DLOPA} \times DLOPA_{i,t} + \beta_{MktQualIns} \times MktQualIns_{i,t} + e_{mi,t} \qquad \text{(Eq. 1)}$$

$$DLOPA_{i,t} = \beta_{MktQuality} \times MktQuality_{i,t} + \beta_{DLOPAIns} \times DLOPAIns_{i,t} + e_{di,t} \qquad \text{(Eq. 2)}$$

	EQUATION 1				EQUATION 2			
	Volatility	QuoSprd	EffSprd	LOBDepth	DLOPA			
DLOPA	-0.0497*	-0.3208**	-0.2260***	0.0223***				
	(0.0287)	(0.1155)	(0.0541)	(0.0030)				
MktQualIns	0.1092***	0.1146***	0.0789**	-0.0013**				
	(0.0396)	(0.0289)	(0.0263)	(0.0007)				
DLOPAIns					0.1653***	0.1694*	0.1912**	0.1450***
					(0.0093)	(0.0669)	(0.0577)	(0.0535)
Volatility					0.2807***			
					(0.0501)			
QuoSprd						0.3635		
						(0.5588)		
EffSprd							0.4750	
							(0.5825)	
LOBDepth								-0.3863
								(1.1530)

The results once again show significantly negative estimates for β_{DLOPA} where short-term volatility, quoted spread and effective spread variables are used as market quality measures. The estimate is significantly positive when the depth of the limit order book is used as a benchmark for market quality. This result indicates that a strong and consistent relationship can be observed even in the stock-by-stock level. The findings confirm that higher dynamic limit order placement activities improve market quality by reducing the short-term volatility as well as improving liquidity levels by narrowing the spreads and enhancing the depth of the limit order book. The estimates of $\beta_{MktQuality}$ also show the expected signs at the stock-by-stock level, even though the statistical significance levels (as observed in the median coefficient estimates) are not as strong as in the larger samples. The coefficient estimates are positive for volatility and spreads, while negative for limit-order-book depth. Even with a relatively lower power, it can still be suggested that dynamic order activities respond to market conditions in such a way that whenever the market quality worsens (heightened volatility, reduced liquidity), traders become more active in their limit order placement activities, including revising or cancelling their submitted orders.

4.5. Effects on the Stock Market with Reduced Latency

4.5.1. Effects on the Stock Market following ASX's Migration from SEATS to ITS

The decision by ASX to migrate its trading platform from SEATS to ITS in October 2006 significantly reduced the market latency and encouraged more intensive trading activities, especially those conducted by algorithmic/high-frequency trading. *Table 4.8* presents the empirical results for the study of dynamic limit order placement activities and how they affect stock market quality using the data sample of August 2007 which is the period post ASX's migration to ITS. The coefficient estimates are reported for each variable together with their significance levels. The standard errors are included in the parentheses.

First of all, the estimation results for *Eq. 2* of the simultaneous equation model in this period show some consistency with those in the period prior to the structural change. In particular, the estimates for the coefficient of interest, $\beta_{MktQuality}$, are positive and statistically significant when short term volatility, quoted spread and effective spread are used as market quality measures. It therefore suggests that when the market condition becomes more volatile or liquidity level drops as spreads are widened, traders are more motivated to increase their order placement activities. The coefficient estimate of $\beta_{MktQuality}$ is significantly negative when the depth of the limit order book is used as a measure of market quality. This negative relationship suggests that when the market turns illiquid with a reduced depth in the limit order book, traders respond by increasing their order placement activities, including revising or cancelling their submitted orders. The results in *Eq. 2* once again indicate that a low quality market environment tends to encourage higher level of limit order activities.

The empirical results of *Eq. 1*, however, reveal some interesting effects that trading activities have on the stock market. The coefficient β_{DLOPA} is estimated separately for each market quality measure and the parameter estimates are presented in *Table 4.8*.

Table 4.8: Effects of Dynamic Limit Order Placement Activities on Market Quality in the ITS Sample Period (August 2007)

This table presents the empirical results for the study of dynamic limit order placement activities and how they affect stock market quality using the full data sample of the period after ASX migrates its platform from SEATS to ITS. *Volatility* measures the short term volatility in the market. *QuoSprd* measures the level of liquidity, calculated as time-weighted average of the quoted bid/ask spreads. *EffSprd* also measures the level of liquidity, but 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-minute interval. The empirical model employs two instrumental variables for market quality and dynamic limit order placement activities, namely, *MktQualIns* and *DLOPAIns* respectively. The coefficient estimates are presented for each of the variable and the standard errors are reported in the parentheses. ***, **, * denote statistical significance at the 1, 5 and 10 percent level respectively.

	EQUATION 1				EQUATION 2			
	Volatility	QuoSprd	EffSprd	LOBDepth	DLOPA			
DLOPA	0.0636*** (0.0163)	0.0228 (0.0190)	0.0009 (0.0179)	-0.0186*** (0.0020)				
Vol_Ins	0.5499*** (0.0056)							
QS_Ins		0.2930*** (0.0056)						
ES_Ins			0.4390*** (0.0057)					
LOBD_Ins				0.9949*** (0.0006)				
DLOPAIns					0.2750*** (0.0053)	0.2778*** (0.0055)	0.2800*** (0.0054)	0.2771*** (0.0054)
Volatility					0.3699*** (0.0094)			
QuoSprd						0.3139*** (0.0185)		
EffSprd							0.3597*** (0.0123)	
LOBDepth								-0.0174*** (0.0054)

Table 4.8 shows a positive and significant coefficient estimate of β_{DLOPA} when volatility is used as a measure for market quality. This result suggests that an increase in order placement activities influences the market in such a way that it actually increases short term volatility of the stock. The coefficient estimates of β_{DLOPA} are also positive when quoted spread and effective spread are used as market quality measures. Therefore, it seems to imply that a higher level of order placement activities widens the trading spreads, so it reduces the liquidity of the stock. This effect, however, is not statistically significant in the pooled sample of this study period. When the depth of the limit order book is used as a measure for market quality, the coefficient estimate of β_{DLOPA} is negative and significant. This significantly negative relationship suggests that an increase in order activities actually lowers the liquidity level by decreasing the depth of the limit order book. Consequently, the empirical results of *Eq. 1* in *Table 4.8* show that an increase in dynamic limit order placement activities leads to a reduction in the stock market quality. This outcome is observed from a higher volatility and a lower level of liquidity (larger spreads and a reduced depth). This result is interesting because it seems to indicate an opposite effect that order activities have on the market post ASX's migration to ITS compared to the prior period.

The findings of this section's analysis are, indeed, consistent with the previous literature in term of traders' response to the stock market conditions. Other studies also find that traders become more aggressive when the own (opposite) side book is thicker (thinner), the spread is wider, and the temporary volatility increases (Ranaldo, 2004). This section provides an additional insight into the interactions between order activities dynamically managed by traders and the market environment where the orders are submitted. The empirical results signify that even after the migration of ASX from SEATS to ITS, traders still respond to stock market conditions in a similar way as the previous period. Specifically, as the market quality worsens, the level of dynamic limit order activities gradually increases. However, as these activities intensify, they do not help improve the quality of the stock market as previously, but they rather make the situation worse by raising the short-term volatility and lowering the liquidity level (as evidenced in *Eq. 1*). The effect is particularly true when the trading environment is characterised as low-latency with the domination of high-frequency trading. This finding is, in fact, consistent with Gai et al. (2012) 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.

4.5.2. DLOPA of Large Stocks vs Small Stocks following ASX's Migration from SEATS to ITS

Similar to the previous chapter, the data sample is divided into large-capitalisation and small-capitalisation stocks and the empirical model is estimated for each sample separately for the data period after ASX migrates its platform from SEATS to ITS. *Table 4.9* reports the estimation results for the sample of large-cap stocks while the estimation results for the sample of small-cap stocks are presented in *Table 4.10*.

Table 4.9: Effects of Dynamic Limit Order Placement Activities of Large Stocks on Market Quality in the ITS Sample Period (August 2007)

This table presents the empirical results for the study of dynamic limit order placement activities and how they affect stock market quality using the data sample of large capitalisation stocks in the period after ASX migrates its platform from SEATS to ITS. *Volatility* measures the short term volatility in the market. *QuoSprd* measures the level of liquidity, calculated as time-weighted average of the quoted bid/ask spreads. *EffSprd* also measures the level of liquidity, but 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-minute interval. The empirical model employs two instrumental variables for market quality and dynamic limit order placement activities, namely, *MktQualIns* and *DLOPAIns* respectively. The coefficient estimates are presented for each of the variable and the standard errors are reported in the parentheses. ***, **, * denote statistical significance at the 1, 5 and 10 percent level respectively.

	EQUATION 1				EQUATION 2			
	Volatility	QuoSprd	EffSprd	LOBDepth	DLOPA			
DLOPA	0.0697***	0.0374**	0.0144	-0.0139***				
	(0.0146)	(0.0167)	(0.0158)	(0.0017)				
Vol_Ins	0.5294***							
	(0.0067)							
QS_Ins		0.2778***						
		(0.0076)						
ES_Ins			0.4164***					
			(0.0072)					
LOBD_Ins				0.9947***				
				(0.0008)				
DLOPAIns					0.4501***	0.4531***	0.4533***	0.4535***
					(0.0070)	(0.0070)	(0.0070)	(0.0070)
Volatility					0.1400***			
					(0.0131)			
QuoSprd						0.0444*		
						(0.0253)		
EffSprd							0.1395***	
							(0.0169)	
LOBDepth								-0.0271***
								(0.0071)

Table 4.10: Effects of Dynamic Limit Order Placement Activities of Small Stocks on Market Quality in the ITS Sample Period (August 2007)

This table presents the empirical results for the study of dynamic limit order placement activities and how they affect stock market quality using the data sample of small capitalisation stocks in the period after ASX migrates its platform from SEATS to ITS. *Volatility* measures the short term volatility in the market. *QuoSprd* measures the level of liquidity, calculated as time-weighted average of the quoted bid/ask spreads. *EffSprd* also measures the level of liquidity, but 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-minute interval. The empirical model employs two instrumental variables for market quality and dynamic limit order placement activities, namely, *MktQualIns* and *DLOPAIns* respectively. The coefficient estimates are presented for each of the variable and the standard errors are reported in the parentheses. ***, **, * denote statistical significance at the 1, 5 and 10 percent level respectively.

	EQUATION 1				EQUATION 2			
	Volatility	QuoSprd	EffSprd	LOBDepth	DLOPA			
DLOPA	0.0295***	-0.0106	0.0095	-0.0076***				
	(0.0107)	(0.0124)	(0.0116)	(0.0010)				
Vol_Ins	0.6058***							
	(0.0063)							
QS_Ins		0.4077***						
		(0.0072)						
ES_Ins			0.5106***					
			(0.0068)					
LOBD_Ins				0.9987***				
				(0.0006)				
DLOPAIns					0.5813***	0.5843***	0.5823***	0.5851***
					(0.0064)	(0.0064)	(0.0064)	(0.0063)
Volatility					0.1229***			
					(0.0105)			
QuoSprd						0.1494***		
						(0.0158)		
EffSprd							0.1112***	
							(0.0126)	
LOBDepth								0.1791***
								(0.0063)

The results in *Eq. 1* generally show consistent coefficient estimates for β_{DLOPA} in the two samples of large and small stocks for the ITS period. The signs of the coefficient estimates are mostly in harmony with the pooled sample, even though the effects are more statistically and economically significant for the large sample than they are for the small sample. The results indicate that a higher level of order placement activities conducted by traders does not improve market quality. In fact, an increase in order activities rather heightens short term volatility as well as reduces liquidity for both large and small stocks by widening the spreads and lowering the depth of the limit order book. *Eq. 2* also shows generally consistent results for the estimations of the coefficient $\beta_{MktQuality}$. Most of the parameter estimates of this coefficient in both samples of small stocks and large stocks confirm the intuition that has been evidenced from the pooled sample. In particular, the estimates of $\beta_{MktQuality}$ are positive and statistically significant when volatility, quoted spread and effective spread are used as market quality measures. There is, however, an exception for the case of small stocks sample that makes it different to the large stocks as well as the pooled sample. When the depth of limit order book is used as a measure for market quality, the estimate of $\beta_{MktQuality}$ is significantly positive for the small stocks, while it is negative and significant for the large stocks. This effect seems to suggest that small stocks respond somewhat differently to large stocks when the supply of limit orders in the order book changes. Nevertheless, the results of *Table 4.9* and *Table 4.10* still indicate that overall traders respond to market conditions by increasing their level of dynamic limit order placement activities whenever there is a decline in the quality of the stock market.

4.5.3. Effects on the Stock Market following the Launch of ASX Trade

In November 2010, ASX launched its new trading platform, which is called ASX Trade. This structural change reduced the market latency even further. This section discusses dynamic order placement activities following the inception of ASX Trade and the effects that these activities have on the quality of the stock market. *Table 4.11* reports the parameter estimates for the empirical model using the data sample of the year post ASX Trade (August 2011). The coefficient estimates are presented separately for each variable together with their significance levels. The standard errors are included in the parentheses.

Table 4.11: Effects of Dynamic Limit Order Placement Activities on Market Quality in the ASX Trade Sample Period (August 2011)

This table presents the empirical model estimations for the study of dynamic limit order placement activities and how they affect stock market quality using the full data sample of the period following the launch of ASX Trade. *Volatility* measures the short term volatility in the market. *QuoSprd* measures the level of liquidity, calculated as time-weighted average of the quoted bid/ask spreads. *EffSprd* also measures the level of liquidity, but 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-minute interval. The empirical model employs two instrumental variables for market quality and dynamic limit order placement activities, namely, *MktQualIns* and *DLOPAIns* respectively. The coefficient estimates are presented for each of the variable and the standard errors are reported in the parentheses. ***, **, * denote statistical significance at the 1, 5 and 10 percent level respectively.

	EQUATION 1				EQUATION 2			
	Volatility	QuoSprd	EffSprd	LOBDepth	DLOPA			
DLOPA	0.0238***	0.0104	0.0043	-0.0083***				
	(0.0075)	(0.0081)	(0.0081)	(0.0007)				
Vol_Ins	0.5760***							
	(0.0047)							
QS_Ins		0.4970***						
		(0.0049)						
ES_Ins			0.4994***					
			(0.0049)					
LOBD_Ins				0.9972***				
				(0.0004)				
DLOPAIns					0.5982***	0.5978***	0.5983***	0.5972***
					(0.0044)	(0.0045)	(0.0045)	(0.0045)
Volatility					0.2955***			
					(0.0076)			
QuoSprd						0.1119***		
						(0.0090)		
EffSprd							0.2184***	
							(0.0090)	
LOBDepth								-0.0412***
								(0.0045)

The coefficient estimates of β_{DLOPA} in the first equation (*Eq. 1*) are relatively consistent with the sample period post ITS in 2007, especially regarding signs and statistical significance. Specifically, *Table 4.11* shows a significantly positive coefficient estimate of β_{DLOPA} when volatility is used as a measure for market quality. The coefficient estimates of β_{DLOPA} are also positive when quoted spread and effective spread are used as market quality measures, even though the effects are not statistically significant. When the depth of the limit order book is employed as a market quality measure, the simultaneous equation model obtains a negative and significant coefficient estimate of β_{DLOPA}. These results imply that an increase in the level of order placement activities raises the short term volatility and reduces the level of liquidity in the market. This effect also confirms the intuition that a higher level of order placement activities in fact worsens the quality of the stock market. This finding is, once again, consistent with Gai et al. (2012). Besides, it is also worth noting that even though the signs and statistical significance of the coefficient estimates are consistent for both periods before and after the launch of ASX Trade, the levels of economic significance are not the same for the two periods. Specifically, the coefficient estimates in *Eq. 1* of the sample period in 2011 have smaller magnitudes compared to the period in 2007. In other words, the results indicate that an increase in dynamic limit order placement activities following the inception of ASX Trade also worsens the quality of the stock market. However, the effects are not as severe as being observed in the period which immediately follows the migration of the exchange to ITS. The findings, therefore, seem to suggest that with technological improvements of ASX Trade, in the later periods the ASX becomes more efficient than before in term of limiting the adverse effects caused by intense trading activities, especially the high-frequency trading in the low-latency environment.

Table 4.11 also shows consistent results for coefficient estimates in *Eq. 2* of the simultaneous equation model. In particular, the estimates of $\beta_{MktQuality}$ are positive and significant when short term volatility, quoted spread and effective spread are used as measures of market quality, whereas the coefficient estimate is significantly negative when the depth of the limit order book is employed as a quality measure. Consequently, the results suggest that a decline in market quality, characterised by higher volatility and lower liquidity, tends to prompt traders to increase their order placement activities. It is again interesting to note that the majority of the coefficient estimates in *Eq. 2* for the sample period post ASX Trade are not as economically significant as those in the sample period which immediately follows the exchange's migration to ITS. This observation seems to signify that traders in the period of ASX Trade are less sensitive to the deterioration in the quality of the stock market compared to the prior period.

4.5.4. DLOPA of Large Stocks vs Small Stocks following the Launch of ASX Trade

For a complete comparison, the data sample in the period following the launch of ASX Trade is also divided into two samples of large-cap and small-cap stocks; and each of the two samples is examined separately. The estimation results of the simultaneous equation model for the sample of large-cap stocks are reported in *Table 4.12* while the results for the sample of small-cap stocks are presented in *Table 4.13*.

Table 4.12: Effects of Dynamic Limit Order Placement Activities of Large Stocks on Market Quality in the ASX Trade Sample Period (August 2011)

This table presents the empirical model estimations for the study of dynamic limit order placement activities and how they affect stock market quality using the data sample of large capitalisation stocks in the period after the launch of ASX Trade. *Volatility* measures the short term volatility in the market. *QuoSprd* measures the level of liquidity, calculated as time-weighted average of the quoted bid/ask spreads. *EffSprd* also measures the level of liquidity, but 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-minute interval. The empirical model employs two instrumental variables for market quality and dynamic limit order placement activities, namely, *MktQualIns* and *DLOPAIns* respectively. The coefficient estimates are presented for each of the variable and the standard errors are reported in the parentheses. ***, **, * denote statistical significance at the 1, 5 and 10 percent level respectively.

	EQUATION 1				EQUATION 2			
	Volatility	QuoSprd	EffSprd	LOBDepth	DLOPA			
DLOPA	0.0266***	0.0127	0.0051	-0.0092***				
	(0.0079)	(0.0084)	(0.0084)	(0.0009)				
Vol_Ins	0.5618***							
	(0.0065)							
QS_Ins		0.4911***						
		(0.0069)						
ES_Ins			0.4848***					
			(0.0069)					
LOBD_Ins				0.9950***				
				(0.0008)				
DLOPAIns					0.8211***	0.8214***	0.8218***	0.8217***
					(0.0045)	(0.0045)	(0.0045)	(0.0045)
Volatility					0.1478***			
					(0.0080)			
QuoSprd						0.0119		
						(0.0092)		
EffSprd							0.0721***	
							(0.0093)	
LOBDepth								-0.0610***
								(0.0045)

Table 4.13: Effects of Dynamic Limit Order Placement Activities of Small Stocks on Market Quality in the ASX Trade Sample Period (August 2011)

This table presents the empirical model estimations for the study of dynamic limit order placement activities and how they affect stock market quality using the data sample of small capitalisation stocks in the period after the launch of ASX Trade. *Volatility* measures the short term volatility in the market. *QuoSprd* measures the level of liquidity, calculated as time-weighted average of the quoted bid/ask spreads. *EffSprd* also measures the level of liquidity, but 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-minute interval. The empirical model employs two instrumental variables for market quality and dynamic limit order placement activities, namely, *MktQualIns* and *DLOPAIns* respectively. The coefficient estimates are presented for each of the variable and the standard errors are reported in the parentheses. ***, **, * denote statistical significance at the 1, 5 and 10 percent level respectively.

	EQUATION 1				EQUATION 2			
	Volatility	QuoSprd	EffSprd	LOBDepth	DLOPA			
DLOPA	0.0179**	0.0001	0.0126	-0.0030***				
	(0.0082)	(0.0086)	(0.0081)	(0.0003)				
Vol_Ins	0.5990***							
	(0.0063)							
QS_Ins		0.5536***						
		(0.0066)						
ES_Ins			0.6173***					
			(0.0062)					
LOBD_Ins				0.9995***				
				(0.0002)				
DLOPAIns					0.7694***	0.7689***	0.7682***	0.7690***
					(0.0050)	(0.0050)	(0.0050)	(0.0050)
Volatility					0.1159***			
					(0.0084)			
QuoSprd						0.0554***		
						(0.0091)		
EffSprd							0.0464***	
							(0.0082)	
LOBDepth								-0.0261***
								(0.0050)

Consistently with the pooled sample, the empirical results of *Eq. 1* for both samples of large and small stocks indicate that a higher level of order placement activities conducted by traders does not help improve market quality. Particularly, short term volatility is raised and level of liquidity is reduced when there are a larger number of order placement activities. This intuition is shown by a positive and significant coefficient estimate of β_{DLOPA} when *Volatility* is used as a measure for market quality, whereas the estimate is negative and significant when *LOBDepth* is used as a quality measure. The effects are positive but not as statistically significant when *QuoSprd* and *EffSprd* are employed in *Eq. 1*. Similarly, the estimation results of *Eq. 2* for both samples of small and large stocks also confirm the findings established for the pooled sample. Specifically, the parameter estimates of $\beta_{MktQuality}$ are positive and mostly significant when market quality is measured by short term volatility, quoted spread as well as effective spread; while this estimate is significantly negative when the depth of the limit order book is used as a quality measure. Therefore, whenever the quality of the stock market declines, i.e. more volatile or less liquid, traders are more encouraged to respond by increasing their limit order placement activities. Unlike the period post ITS in 2007, in this period following the inception of ASX Trade, all of the effects are in line with the pooled sample, even for the sample of small-cap stocks.

Moreover, it is also worth noting the differences in terms of economic significance of the coefficient estimates for the two equations in the two samples of large and small stocks. In *Eq. 1*, most of the estimates of β_{DLOPA} in the sample of large stocks have larger absolute magnitudes than those in the sample of small stocks. It is, indeed, evident that in this period following the launch of ASX Trade, the adverse effects of order placement activities (in dampening the market quality) are more severe for large stocks than for small stocks. This is an interesting finding as this comparison is, in part, a reversal of what is found in the early period of the ASX200. In particular, the earlier period (year 2000) views dynamic order placement activities with a greater and more significant effect for small stocks than for large stocks, especially when considering the effect on short term volatility of the market. Similarly, in the period of ASX Trade, the estimates of $\beta_{MktQuality}$ for the sample of large stocks are also generally more economically significant than the estimates for the sample of small stocks. This observation implies that when the market quality declines, order placement activities are intensified at a greater degree for the large stocks than for the small stocks. In other words, following the structural change of the ASX with technological improvements and a significant reduction in market latency, it is evident that traders of larger stocks are more responsive to the conditions of the market, than those trading smaller stocks. This finding is again considered as a reversal of the earlier period of the exchange (year 2000). It can be explained by the fact that larger trades in this ASX Trade period experience larger opportunity costs. As a result, they require closer and more active monitoring procedures (see, for example, Liu, 2009). For this reason, a larger extent of order placement activities is required for larger stocks whenever market conditions alter against traders' initial expectations.

4.6. 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 have 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. The study in this chapter shows that traders dynamically manage their order placement activities in an attempt to respond to certain stock market conditions. Specifically, when the market becomes more volatile or less liquid, traders are more motivated to intensify their order placement activities, including revising or cancelling their submitted limit orders. The results also suggest that for a given change in market conditions, traders increase their activities at a greater extent for small stocks than for large stocks in the early period of ASX200. This effect, however, reverses after the structural changes of the ASX where its latency is reduced significantly. In the later sample periods, especially in the ASX Trade (post 2010) period, dynamic order placement activities of larger stocks are more sensitive to changes in the levels of volatility and liquidity of the market. Traders are, therefore, required to be more active in monitoring their submitted limit orders, especially when the market conditions alter adversely. Further analysis at the stock-by-stock level also confirms this chapter's findings on the interactions between dynamic limit order placement activities and stock market quality.

Furthermore, this chapter finds that dynamic order placement activities directly affect the quality of the stock markets. In particular, in the earlier period, traders respond to a low quality market, i.e. one that is characterised by lower liquidity and higher volatility, by increasing their limit order placement activities. An increase of traders' activities, including revising and cancelling their submitted limit orders, helps improve the market quality by reducing short-term volatility, narrowing the spreads and enhancing the depth of the limit order book. However, this effect is no longer observed in the periods following the structural changes of the ASX. Specifically, as the level of limit order placement activities increases, a more turbulent stock market is also created where liquidity is reduced and volatility is heightened. This result can be attributed to the amount of algorithmic/high-frequency trading that is increased when trading activities intensify. As a result, the net impact is a lower market quality, which is an opposite effect to the earlier period. Nevertheless, as technology is improved and market latency is lowered, the adverse influences of the order placement activities are reduced, as evident in the period of ASX Trade (2011) compared to the ITS period (2007).

This study contributes to the current literature of market microstructure in two important aspects. The first major contribution is the examination of limit order revision and cancellation as part of a trader's strategy in dynamically managing their trading activities. Most of the previous studies on order choice and placement activities have primarily focused on order submission and execution and largely disregarded the activities of order revision and cancellation. This chapter, on the other hand, construct measures of trading activities as full series of order submission, revision, execution as well as cancellation of buy/sell limit orders. The second key contribution of this chapter is the study of the interactions between dynamic limit order placement activities and stock market quality, taking into account non-arbitrary linkages of limit order events.

A lower latency trading environment provides means for more developments of technology and efficient trading algorithms. Nevertheless, a high-frequency trading 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 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.

CHAPTER 5

MULTIPLE DURATION ANALYSES OF DYNAMIC LIMIT ORDER PLACEMENT STRATEGIES AND AGGRESSIVENESS IN A LOW-LATENCY MARKET ENVIRONMENT

5.1. Introduction

The reductions in latency by stock exchanges around the world, together with innovations in technology, have encouraged more rapid developments of trading algorithms. Algorithmic traders have played a very important role in financial markets in the recent years. They have facilitated the trading activities of large institutional as well as individual traders. The Australian Stock Exchange (ASX) is a popular example with its decision to migrate its platform from SEATS to ITS in October 2006 which significantly reduced latency in the exchange from 85 to 30 milliseconds. Later, in November 2010, ASX made another move in launching the ASX Trade which lowered market latency even further.

The existing literature on order placement activities has largely overlooked the option to cancel or revise prevailing limit orders. Order revisions and cancellations constitute an important area of study in market microstructure since a significant number of limit orders on the ASX, the NYSE, or the London Securities and Derivatives Exchange are amended or cancelled following their submission (see, for example, Coppejans and Domowitz, 2002; Yeo, 2006; Fong and Liu, 2010). In addition, with the speedy developments of trading technology, not only the number but also the frequency of order revisions and cancellations has also increased rapidly. Hasbrouck and Saar (2009) find that 'fleeting orders'[9] on INET account for 36% of limit order submissions in 2004. This value is twice the rate calculated in 1999. Hendershott et al. (2011) also reveal that the orders-to-trades ratio, which indicates the intensity of order cancellations, rose significantly in 2003 following a structural change in the NYSE towards market automation.

[9] 'Fleeting orders' are defined by Hasbrouck and Saar (2009) as the limit orders which are cancelled within two seconds of being submitted into the order book.

The rapid improvements in technology and market latency have resulted in an arms race of algorithmic and high-frequency trading, which contributed to the stock market flash crash in May 2010. Hasbrouck and Saar (2009), amongst a number of other researchers, have identified strategic orders that are submitted and removed from the market very quickly. 'Fleeting orders' are an example of such strategic orders. Their research paper, however, only studies order cancellations using a single duration model. Therefore, one of the most important contributions of this thesis chapter is the application of an empirical model that provides a more comprehensive study of limit order placement strategies and their aggressiveness by examining all order events, including limit order cancellation and order revisions, as well as aggressive and defensive revisions. A multiple duration model is employed for the purpose of this study to take into account duration dependence since limit order cancellation and revision are single events from a sequence of multiple events. The research is conducted for the period immediately followed ASX's migration to ITS as well as the period subsequent to the launch of ASX Trade.

The results of this chapter support the findings in the previous chapters on the response of dynamic limit order placement strategies to changes in the conditions of the stock market. Traders respond to a lower quality of the market by intensifying their activities of order cancellation and order revisions, including aggressive and defensive revisions. In particular, the probability of occurrence of order cancellation and revision activities is found to be higher when there is a higher level of short term volatility and a lower level of liquidity, as well as when there are more fleeting orders in the exchange. The results of this chapter also indicate that a higher initial aggressiveness of submitted limit orders leads to a higher hazard rate of order cancellation and a lower hazard rate of order revision. Moreover, the evidence seems to imply that traders have a higher tendency to cancel their limit order and submit a more aggressive one, or to revise their limit order with a more aggressive price when the same-side quote moves adversely away from the initial price. By following such strategies, traders in fact ‘chase the market’ to gain better execution opportunities. This result is indeed consistent with the ‘chasing hypothesis’ discussed in the research of Hasbrouck and Saar (2009). In addition, the ASX Trade period reveals that when the opposite quotes become cheaper, traders are more eager to cancel their existing limit orders to opt for market orders with an immediate execution. This evidence is significant because it provides a strong support for the 'cost of immediacy hypothesis’. Furthermore, the empirical results seem to suggest that submitting an aggressive limit order for a small-cap stock generally has a statistically less significant effect on the hazard rates of order cancellation and order revisions, including aggressive and defensive revisions, than for a large-cap stock.

Chapter 5 proceeds as the followings. *Section 5.2* introduces the low-latency stock market environment and discusses related studies in the current literature regarding this area of research. *Section 5.3* presents the limit order data used for the purpose of this study. *Section 5.4* describes the empirical methodology employed including the constructions of explanatory variables. *Section 5.5* presents a discussion of the empirical results and explains why the study findings are interesting and important. Finally, *Section 5.6* concludes the chapter.

5.2. The Low-Latency Stock Market Environment

In the recent periods, real time market and news monitoring have become increasingly feasible. This is attributable to the technology developments that allow financial markets around the world to improve trading latency significantly. Latency can be understood as the required time to realise an event which occurs in the market, produce an analysis, and have the securities exchange take action upon that accordingly. Exchanges around the world have made large investments towards improving their platforms with an effort to lower the communication time with investors in handling their orders. Traders have also been offered the option to place their trading computers close to the exchanges in order to cut the transmission times to as low as under a millisecond. Investments in technology have been conducted not only by exchanges, but also by traders themselves in an attempt to respond to information and to trade upon it quicker. Therefore, the low-latency stock market environment has been characterised by an increased speed of not only absorbing the arriving information, but also taking actions upon such news. Due to the fundamental volatility of many types of financial securities and their rapidly changing prices in the market, it is highly significant for traders to improve their speed of trading. Being able to trade faster than other traders is a very important advantage since it can create potential profit opportunities by enabling a prompt response to the arriving news of the market. This observation creates an arms race in which traders utilise technology innovations and position their trading computers closer to the exchange location with an effort to gain access to the market quicker. As a result, it can be observed in the financial markets today that there are intensive activities in the low-latency market environment. Hasbrouck and Saar (2013) provide an interesting research on the low-latency trading activities which involve automated traders who act in response to each other in the millisecond environment. They find that an increase in the level of low-latency activities actually improves traditional market quality measures.

There is a significant amount of trading that has been carried out by machines (also known as algorithmic trading) to reduce the labour effort devoted to monitoring activities. Human traders are likely to have a more comparative advantage over machines in more complex situations. However, machines have the advantage of responding more quickly to the arrival of information, working out an optimal solution quicker based on a number of input parameters. Besides, machines have virtually unlimited information processing capacity and therefore can be very useful and preferable to human trading in many circumstances. With better access to markets and information via electronic connections, algorithmic trading has led to a significant reduction in monitoring cost. This also helps reducing the submission risks for limit orders. On the other hand, as mentioned above, these advantages of automated trading also give rise to algorithmic arms race between competing trading firms. There have been a growing number of empirical studies in the literature regarding the examination of the speed of trading in financial markets. Some examples include Hendershott and Moulton (2011) and Riordan and Storkenmaier (2012) who investigate technology innovations of securities markets that lead to a reduction in latency. The studies, however, find controversial evidence regarding the effects of such innovations on the quality of the market.

In regards to algorithmic trading, there are a number of studies on high-frequency trading (HFT) which exists in various markets and trading platforms around the world. Some popular examples include: Jovanovic and Menkveld (2011) and Menkveld (2011) examine the Euronext and Chi-X exchanges; Chaboud et al. (2014)

investigate the inter-dealer foreign exchange market; and Kirilenko et al. (2014) conduct a study on HFT in the futures market. In addition, various research papers study HFT in the Deutsche Boerse (see, for example, Gsell, 2008; Gsell and Gomber, 2008; Prix et al., 2007) and a number of other studies investigate the impacts of HFT on various aspects of the U.S. markets (see, for example, Hendershott et al., 2011; Hendershott and Riordan, 2013). Riordan and Storkenmaier (2012) is another interesting study which finds that a reduction in latency on the Xetra system of the Deutsche Boerse is associated with improved liquidity. On the other hand, Hendershott and Moulton (2011) examine NYSE's Hybrid Market[10] and conclude that a reduced latency causes a lower level of liquidity, but helps improve informational efficiency.

The recent literature on high-frequency trading strives for establishing facts on algorithmic activities and for an evaluation of the impacts of these activities on financial markets. Cespa and Foucault (2008) and Easley et al. (2010) construct theoretical models which allow for a delay in observing information from the market by some traders. Pagnotta and Philippon (2013) study speed as one important element which differentiates one securities exchange from another. Moallemi and Saglam (2010) examine the various placement strategies for a sell limit order in an attempt to find an optimal strategy when there are random arrivals of buy limit orders[11]. Meanwhile, Gsell (2008) investigates algorithmic trading activities on the German Xetra system and demonstrates that a large proportion of such traders are not liquidity suppliers. These traders send orders to demand for liquidity instead. However their orders are not as large as the orders submitted by regular traders. Other related studies in this field apply

[10] The Hybrid Market of the NYSE was introduced in 2006. The trading platform enhances automatic execution of orders and lowers the time it takes to execute a market order in the NYSE to under a second compared to ten seconds previously.

[11] In Moallemi and Saglam (2010), a pegging strategy is applied for the sell limit order. However, tracking errors could occur because latency may cause a delay in the monitoring process, and this is very costly for the trader.

various modelling techniques in studying the effects of information latency on liquidity, the cost of capital, as well as the efficiency of prices. They have, nevertheless, arrived at mixed conclusions regarding the true impacts. For instance, Boulatov and Dierker (2007) take a perspective from the securities exchanges and examine information latency using a theoretical model. The research finds that selling data on a real-time basis is beneficial in improving information efficiency for prices, but it is also harmful for market liquidity. On the other hand, Boehmer et al. (2014) report that greater intensity of algorithmic trading even though raises short-term volatility, it actually improves liquidity as well as informational efficiency[12]. They also conclude that a higher level of algorithmic trading is associated with a decline in equity capital in the following year, mainly driven by an increase in repurchase activity. Besides, Gsell and Gomber (2008) find strong supports for pegging strategies on the German Xetra, while Prix et al. (2007) show some regular patterns of algorithmic traders in their trading activities. Hendershott and Riordan (2013) uncover that trades executed by algorithms place a greater effect on prices than those which are not executed by algorithms. As a result, they find that algorithmic traders have a larger contribution towards price discovery[13]. Furthermore, algorithmic trading has been observed not only in the stock market but also in the inter-dealer foreign exchange market. Chaboud et al. (2014) study such market and conclude that trading activities by algorithms do not cause an increase in volatility of exchange rates. Hendershott et al. (2011) construct a measure of normalised message count, which can be used as a proxy for algorithmic trading, and show that an increase in algorithmic activities affects liquidity only for large stocks[14].

[12] 42 equity markets are examined in Boehmer et al. (2014) to study the impact of trading algorithms intensity on the measures of market quality.
[13] Hendershott and Riordan (2013) study a sample of 30 stocks on the DAX stock exchange.
[14] Hendershott et al. (2011) employ an event study to examine the NYSE event of the auto quoting establishment in 2003. The study investigates algorithmic traders in this market by relying on the rate of information arrival on the NYSE as a measure of combined agency and proprietary algorithmic activities.

The presence of algorithmic traders helps the large stocks in term of price discovery, also lowers the quoted spread, the effective spread, as well as the quoted depth of the large stocks. Conversely, Hasbrouck and Saar (2013) indicate an enhancement in all market quality measures for both small and large stocks, including improvements in their quoted depth and short-term volatility.

While it appears that intermediated trading is on the rise with the low-latency traders acting as the intermediaries, it is still inconclusive whether an intensive level of low-latency activities is in fact destructive or beneficial for financial markets. In other words, the existing literature has not satisfactorily provided evidence to answer the question of whether trading activities in the low-latency market environment worsen or improve the quality of financial markets, especially in terms of liquidity and volatility.

5.3. Limit Order Data

The decision by the Australian Securities Exchange (ASX) to migrate its trading platform from Stock Exchange Automated Trading System (SEATS) to Integrated Trading System (ITS) substantially reduced the market latency from 85 to 30 milliseconds. Subsequently, the launch of ASX Trade to replace ITS reduced the exchange latency even further. The migrations of the ASX to more advanced platforms brought interesting trading activities in the periods subsequent to the two structural changes. This chapter conducts an investigation of dynamic limit order placement activities of the 40 index stocks listed on the ASX over the two sample periods that immediately followed the structural changes. Therefore, the two sample periods of year 2007 and year 2011 are chosen for this research. They are the two recent periods that the market began to have the characteristics of a low-latency trading environment. The data for each sample period contains 20 large and 20 small stocks, ranked by market capitalisation. Large-capitalisation stocks are the top 20 common stocks that are traded on the ASX200 index. For the purpose of this study, small-capitalisation stocks are chosen as the 20 common stocks ranked 111th to 130th on the ASX200 index. The ASX had employed a fully computerised Stock Exchange Automated Trading System (SEATS) from 1987. In October 2006, the exchange introduced the Integrated Trading System (ITS) to replace SEATS. ITS is a fully-electronic trading system used for efficient and quick transactions. While it provided several operational improvements over SEATS, it did not change the ASX's market structure or trading rules. Therefore year 2007 is chosen as the sample period for this research as it was the year which immediately followed the inception of ITS. In November 2010, ASX Trade was launched to replace ITS. ASX Trade is an ultra-low latency trading platform. 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, year 2011 is also chosen as a sample period for this research as it was the year that immediately followed the launch of ASX Trade. In each sample period, the month of August is chosen as the month of interest for study as most preliminary end-of-year earnings reports are released in August and more trading activities are expected as a result. The data samples record each order and trade details, including the date, time, stock code, price, transacted volume and order types. The type of order, such as submission, revision, execution, or cancellation is recorded for each order event. The dataset is provided by the Securities Industry Research Centre of Asia-Pacific (SIRCA).

5.4. Empirical Methodology

5.4.1. Empirical Model Specification and Approach

Chapter 5 examines the periods when the ASX experiences low latency and studies the characteristics, effects and levels of aggressiveness of dynamic limit order placement activities in the market. This chapter contributes to the current literature by extending the existing investigations to examine the multiple events that happen in the entire life of limit orders. This objective is achieved by utilising a survival analysis methodology with a multiple-spell duration model. To the best of my knowledge, this thesis is the first research to provide an examination of dynamic limit order placement strategies and aggressiveness in a low-latency market environment using a multiple-spell duration model approach.

Subsequent to the submission of a limit order to buy or sell a stock, the limit order can be executed within a short or long period of time depending on a number of factors, including the order's aggressiveness. If the order is not picked up, the trader then has the option to cancel or revise the limit order. The revised order can be left until execution or it may also be revised multiple times following the first revision. Using the order reference number and time, we can track execution, revision and cancellation order events that follow an order submission or that are subsequent to an order revision. As being explained in the previous chapter, many orders in the sample of study experience more than one event subsequently to their initial submission into the limit order book. In fact, close to 97% of buy orders experience up to 5 events following their submission, and a similar percentage is also observed for sell orders (as shown in *Table 3.1*). As a result, it is more appropriate to employ survival analysis with a multiple-spell duration model since they allow the duration of an event to be dependent, not only on the order characteristics, but also on the preceding events and their durations.

Proportional Hazard (PH) multiple-spell duration model and its special cases are probably the most well-known duration models based on a specification of the hazard function (Van Den Berg, 2001). There are quite a few empirical analyses of PH models with multi-spell duration data in the literature of biomedical science and labour economics. Some examples of the studies which utilise such methodology include Newman and McCullogh (1984) who estimate models for birth intervals using multiple-spell duration data; Ham and Rea (1987) who employ a discrete-time model; and Coleman (1990) who estimates a reduced-form of unemployment duration models. Lillard (1993) and Lillard and Panis (1996) also use a set of multi-spell data to estimate marriage duration models. In addition, Honore (1993) provides a lagged duration dependence specification, where the duration of the first spell enters the hazard of the second spell multiplicatively.

The focus of this chapter is on limit order revision and limit order cancellation. These order events are considered as the events of interest since they are the choices that traders are presented with and they have to decide upon, following the submission or the revision of a limit order. The two limit order events represent the options that traders have to consider as part of their dynamic limit order placement strategies. As a result, the successive events of limit orders examined in this study include (i) submission-to-cancellation, (ii) submission-to-revision, (iii) revision-to-cancellation, (iv) revision-to-revision. In each of the above transitions, the order event in the left-hand side is said to be in the *origin state* and the order event in the right-hand side is said to be in the *destination state*. The chapter focuses on two competing events: limit order cancellation and limit order revision. The two events are considered as competing with each other since they represent the limit order decisions that traders have to make to either revise or cancel their submitted or revised orders. If the market moves against their initial expectation or if other better opportunities arise, traders can only decide between one of the two actions at a time, either revising or cancelling the existing limit order.

In addition to the above, it is also more interesting to look deeper into the insight of the decision to revise a limit order. Therefore, two types of limit order revisions can be considered: aggressive revision and defensive revision. An aggressive order revision is defined for a buy limit order as a limit order which has a price revised upward and a volume that at least stays the same or is revised upward. It is defined for a sell limit order as a limit order which has a price revised downward and a volume that at least stays the same or is revised upward. Conversely, a defensive order revision is defined for a buy (sell) limit order as a limit order which has a price revised downward (upward) and a volume that at least stays the same or is revised downward.

The empirical model of a survival analysis with multiple-spell duration is specified in a similar way to that described in Chapter 3. For each series of limit order events of a stock, a sequence $t_i=\{t_i^c\}$ of adjacent periods of time (spells) spent in different states is observed. The duration spent is denoted by t, the particular series of limit order events occur for an individual stock is denoted by the subscript i and the c^{th} spell in a specific state is denoted by the superscript c. This study utilises a multiple-spell duration model specification similar to that employed in Gagliarducci (2005). The *hazard rate*, θ_{kj}, is defined as the intensity of the transition to the *destination state* (denoted by *j*) after a visit in the *origin state* (denoted by *k*). The function of the *hazard rate*, θ_{kj}, for the series *i* at its c^{th} spell is expressed as the following:

$$\theta_{kj}\left(t_i^c \middle| X_{ikj};\beta\right) = h_{kj}(t_i^c)\exp\,(\beta_{kj}' X_{ikj})v_{ikj} \tag{5.1}$$

where $h_{kj}(t_i^c)$ is a baseline hazard; X_{ikj} is a set of explanatory variables which incorporate both stock market conditions and limit order characteristics that can influence the decisions and strategies for dynamic order placements; and v_{ikj} is a random individual effect to capture the unobserved heterogeneity. The durations or the survival times of limit orders depend on several factors such as limit order price, order size, market depth, market liquidity, etc. It is worth noting that, unlike Chapter 3, the individual covariates X_{ikj} in this chapter are not all fixed to their values at the beginning of each spell. Instead, the explanatory variables are measured at different states and points in time, depending on the objective of each measure. The variables include those that are calculated in the 5 minutes preceding the order events, those that are taken at the beginning of the spells, as well as those that keep track of the market conditions after the spells have begun. The various measures are utilised in order to capture the characteristics of the low-latency market environment where the limit order placement activities take place as well as capturing their evolvement even after the limit orders have been submitted or revised.

5.4.2. Constructions of Explanatory Variables

In the low-latency market environment, order revisions or cancellations are parts of dynamic strategies carried out by high-frequency traders following their submissions or revisions of limit orders. In order to examine such strategies, it is important to relate traders' decisions to developments in market conditions and other factors of interest throughout the lives of limit orders. Therefore, a standard duration model is not suitable for the purpose of this study since all of the explanatory variables in the standard analysis are constructed at the points of limit order submission or revision (i.e. at the beginning of the order spells). As a result, this chapter utilises time-varying covariates and incorporates them in the multiple duration model to analyse dynamic limit order placement strategies and aggressiveness in a low-latency market environment.

Price aggressiveness is an important factor that characterises dynamic order placement strategies. Liu (2009) proposes that traders revise their limit orders to deal with the free-option risk which has a positive relation with price aggressiveness. Hence, it is important to include the measure of the limit order's price aggressiveness in the analysis of order placement strategies.

The definition of price aggressiveness ($p^{Relative}$) [15] for a buy limit order is as the following:

$$p^{Relative}{}_{i,t} = \frac{LimitOrder\,\mathrm{Pr}\,ice_{i,t=0} - BestBid\,\mathrm{Pr}\,ice_{i,t=0}}{BestBid\,\mathrm{Pr}\,ice_{i,t=0}}$$

The definition of price aggressiveness ($p^{Relative}$) for a sell limit order is as the following:

$$p^{Relative}{}_{i,t} = \frac{BestBid\,\mathrm{Pr}\,ice_{i,t=0} - LimitOrder\,\mathrm{Pr}\,ice_{i,t=0}}{BestBid\,\mathrm{Pr}\,ice_{i,t=0}}$$

In addition, the intensity of order cancellation is found in Hasbrouck and Saar (2009) to be positively related to the changes in quotes on the same side of the

[15] This measure is consistent with that employed in Hasbrouck and Saar (2009) for examining the limit order's price aggressiveness at the time of order submission.

submitted limit order. This positive relation is interpreted as evidence suggesting that traders cancel stale orders and resubmit more aggressive ones in an attempt to chase the market. On the other hand, the order cancellation intensity is also found to be negatively related to the changes in quotes on the opposite side of the submitted limit order. This negative relation is regarded as evidence of traders exploiting more favourable opposite quotes by cancelling limit orders to opt for market orders. Accordingly, this chapter also follows Hasbrouck and Saar (2009) to include two time-variant variables, namely Δq^{Same} (change in the same-side quotes) and $\Delta q^{Opposing}$ (change in the opposite side quotes) in the survival analysis.

The definitions of the variables for a buy limit order are as follows:

$$\Delta q^{same}{}_{i,t} = \frac{BestBid\,\mathrm{Pr}\,ice_{i,t} - BestBid\,\mathrm{Pr}\,ice_{i,t=0}}{BestBid\,\mathrm{Pr}\,ice_{i,t=0}}$$

$$\Delta q^{opposing}{}_{i,t} = \frac{BestOffer\,\mathrm{Pr}\,ice_{i,t} - BestOffer\,\mathrm{Pr}\,ice_{i,t=0}}{BestOffer\,\mathrm{Pr}\,ice_{i,t=0}}$$

The definitions of the variables for a sell limit order are as follows:

$$\Delta q^{same}{}_{i,t} = \frac{BestOffer\,\mathrm{Pr}\,ice_{i,t=0} - BestOffer\,\mathrm{Pr}\,ice_{i,t}}{BestOffer\,\mathrm{Pr}\,ice_{i,t=0}}$$

$$\Delta q^{opposing}{}_{i,t} = \frac{BestBid\,\mathrm{Pr}\,ice_{i,t=0} - BestBid\,\mathrm{Pr}\,ice_{i,t}}{BestBid\,\mathrm{Pr}\,ice_{i,t=0}}$$

The empirical model in this chapter also includes *Order Size* as an explanatory variable since it has been documented in the literature that the size of limit orders matters in revision and cancellation decisions. For example, Fong and Liu (2010) find that traders tend to revise large orders more than small orders due to fixed costs of monitoring. The *Order Size* variable is constructed as the following:

$$OrderSize_{i,t} = Log(OrderVolume_{i,t} \times LimitOrder\,Price_{i,t})$$

Another interesting phenomenon that is observed in the low-latency market environment is the large amount of rapid cancellations of limit orders (see, for example, Hasbrouck and Saar, 2009). It is important to understand whether limit orders that are cancelled very quickly are in fact different from the traditional limit orders, where the traditional ones are assumed to be limit orders that stay patiently in the order book and wait for incoming orders to execute. This chapter defines a limit order that is cancelled within two seconds or less as a “fleeting order”. Similar to Hasbrouck and Saar (2009), the explanatory variable *Fleeting Orders* is constructed as the log of the maximum of either one or the number of fleeting orders in the 5 minutes preceding the order spell.

Finally, in order to study the effects of market conditions on the limit order placement strategies of traders, it is necessary to incorporate the measures of market qualities in the empirical model. Therefore, the explanatory variables *Market Depth*, *Volatility*, and *Spreads* are also included to account for the prevailing market conditions prior to the submission of the limit order. The variables are defined as the followings:

The first market condition variable, *Volatility*, measures short term volatility that the stock experiences and is computed as the difference between the highest and the lowest mid-point of the quoted bid/ask spreads in the 5 minutes preceding each order spell. A lower (higher) value of *Volatility* indicates that the market is less (more) volatile and hence a higher (lower) quality market.

$$Volatility_{i,t} = MaxMQ_{i,t} - MinMQ_{i,t}$$

The second market condition variable, *Spreads*, measures the liquidity level currently existing in the market. This is computed as the time-weighted average of the quoted bid/ask spreads in the 5 minutes preceding the order spell. A lower (higher) value of *Spreads* indicates that the market is more (less) liquid and hence a higher (lower) quality market.

$$Spreads_i = \sum_{j=1}^{n} tw_j (QuoAsk_{i,j} - QuoBid_{i,j})$$

The final market condition variable, *Market Depth*, measures the depth of the limit order book. This is another measure of market liquidity and it is computed as the time-weighted average of the number of shares of a stock in the limit order book in the 5 minutes preceding the order spell. A higher (lower) value of *Market Depth* indicates that the market is more (less) liquid and hence a higher (lower) quality market.

$$\text{Market Depth}_i = \sum_{j=1}^{n} tw_j (LOBAsk_{i,j} + LOBBid_{i,j})$$

5.5. Empirical Results and Discussions

5.5.1. Hypotheses for the Existence of 'Fleeting Orders'

There are two relevant hypotheses that explain why many limit orders are cancelled very quickly following their submissions into the system. The first hypothesis refers to fleeting orders as a part of a dynamic trading strategy that traders employ when they observe a reduction in the cost of immediate execution. This hypothesis is called the 'cost of immediacy hypothesis' which describes the trade-off a market participant faces when market conditions change (see, for example, Cohen et al., 1981). When the spread is shortened, the cost of immediate execution decreases, there is a tendency to cancel submitted limit orders in favour of market orders for an immediate execution. This hypothesis also implies that trader of the original limit order is not a patient liquidity provider because the trader cancels the limit order to opt for a market order to avoid the opportunity cost of waiting. This strategy actually combines elements of both supplying of and demanding for liquidity.

The second hypothesis is called the ‘chasing hypothesis’. It proposes that, when prices move away from the original limit price, traders tend to ‘chase the market’ by cancelling the existing limit order to opt for a different limit order with a different price. It means that if traders want to improve the probability of execution, they would cancel their submitted limit order in favour of a more aggressive limit order. The dynamic strategy of utilising ‘fleeting orders’ indicates a certain level of urgency in the trader’s hope to have the orders executed. It creates a third category of limit orders where the order lies between an impatient market order (which requires to be executed immediately at a higher cost), and a traditional limit order (which patiently waits for the preferred price to arrive). Trading strategies employed by high-frequency arbitrage traders may also attempt to earn market-making profits by chasing the market prices. They do so by submitting limit prices close to the prevailing market price. As a result, when the market prices move away from the original position, these traders also chase the new levels by cancelling their existing orders and submitting the new limit orders.

By examining the interaction of the probability of order cancellation (as well as order revision) with movements in the same-side and opposite-side quotes, it is possible to find evidence in support of (or against) the ‘chasing hypothesis’ and the ‘cost of immediacy hypothesis’. For example, when the subsequent bid improves the order price, if a higher intensity is observed for cancellation activities of buy limit orders, then that shows consistent evidence with the ‘chasing hypothesis’.

5.5.2. Integrated Trading System (ITS): The Full Sample under Study

The decision by ASX to migrate its trading platform from SEATS to ITS in October 2006 significantly reduced the market latency from 85 to 30 milliseconds and created a low-latency environment with a higher level of intensive trading activities. The first two tables of this section report the empirical results for the study of dynamic order placement strategies using a multiple duration approach in the period that followed ASX’s migration to ITS. The results for the pooled sample of buy limit orders are presented in *Table 5.1*, while the results for the pooled sample of sell limit orders are presented in *Table 5.2*. Each table of results is divided into two sections associated with two *origin states*, which are order submission and order revision. The coefficient estimates and their significance levels are then reported for each variable in each type of *destination states*, including order cancellation, order revision, aggressive revision and defensive revision. The standard errors are also included in the parentheses.

Table 5.1: Low-Latency Multiple Duration Analysis of Buy Limit Orders in the Pooled Sample of ITS Period

This table presents the results for the multiple-spell duration analysis of buy limit orders in the pooled sample of ITS period. The table describes the study of dynamic limit order placement strategies in a low-latency market environment. The estimation model used in this analysis is the Proportional Hazard model for multiple-spell duration. Definitions of the explanatory variables are given in the text. The coefficient estimates are presented for each of the variable and the standard errors are reported in the parentheses. ***, **, * denote statistical significance at the 1, 5 and 10 percent level respectively.

	Submission				**Revision**			
	Cancellation	*Revision*	*Aggressive Revision*	*Defensive Revision*	*Cancellation*	*Revision*	*Aggressive Revision*	*Defensive Revision*
$p^{Relative}$	0.130***	-0.029***	-0.093***	0.044**	0.150***	0.020***	-0.001	0.034***
	(0.007)	(0.008)	(0.010)	(0.021)	(0.013)	(0.005)	(0.007)	(0.009)
Δq^{Same}	-0.191***	0.007	0.072***	-0.122***	-0.151***	-0.059***	-0.035***	-0.124***
	(0.007)	(0.008)	(0.009)	(0.021)	(0.013)	(0.005)	(0.006)	(0.009)
$\Delta q^{Opposing}$	0.156***	0.852***	1.445***	-0.071	0.111***	0.489***	0.546***	0.776***
	(0.023)	(0.031)	(0.036)	(0.046)	(0.022)	(0.011)	(0.015)	(0.010)
Order Size	0.170***	-0.029***	-0.134***	0.328***	-0.393***	0.308***	0.229***	1.148***
	(0.004)	(0.004)	(0.004)	(0.014)	(0.009)	(0.003)	(0.003)	(0.006)
Fleeting Orders	0.720***	0.377***	0.274***	0.318***	0.527***	0.295***	0.295***	0.249***
	(0.004)	(0.004)	(0.005)	(0.014)	(0.008)	(0.003)	(0.003)	(0.005)
Spreads	0.024***	0.019***	0.014***	0.059***	0.010	0.004	0.002	-0.012
	(0.005)	(0.004)	(0.005)	(0.014)	(0.009)	(0.003)	(0.004)	(0.008)
Volatility	0.078***	0.098***	0.104***	0.038**	0.141***	0.049***	0.074***	-0.191***
	(0.005)	(0.005)	(0.005)	(0.015)	(0.009)	(0.003)	(0.004)	(0.008)
Market Depth	-0.089***	-0.235***	-0.338***	-0.254***	0.382***	-0.117***	-0.304***	-0.225***
	(0.004)	(0.004)	(0.005)	(0.013)	(0.009)	(0.003)	(0.004)	(0.006)
Lagged Duration					-0.011***	-0.001***	-0.001***	0.004***
					(<.001)	(<.001)	(<.001)	(<.001)
Constant	-0.681***	-1.274***	-1.592***	-4.011***	-2.683***	0.198***	-0.029***	-0.776***
	(0.006)	(0.005)	(0.006)	(0.018)	(0.013)	(0.004)	(0.004)	(0.008)
Unobhet	1.644***	1.450***	1.617***	3.252***	2.315***	0.256***	0.329***	0.770***
	(0.003)	(0.004)	(0.005)	(0.015)	(0.014)	(0.003)	(0.004)	(0.006)

Table 5.2: Low-Latency Multiple Duration Analysis of Sell Limit Orders in the Pooled Sample of ITS Period

This table presents the results for the multiple-spell duration analysis of sell limit orders in the pooled sample of ITS period. The table describes the study of dynamic limit order placement strategies in a low-latency market environment. The estimation model used in this analysis is the Proportional Hazard model for multiple-spell duration. Definitions of the explanatory variables are given in the text. The coefficient estimates are presented for each of the variable and the standard errors are reported in the parentheses. ***, **, * denote statistical significance at the 1, 5 and 10 percent level respectively.

	Submission				**Revision**			
	Cancellation	*Revision*	*Aggressive Revision*	*Defensive Revision*	*Cancellation*	*Revision*	*Aggressive Revision*	*Defensive Revision*
$p^{Relative}$	0.001	4.550***	2.774**	2.341***	-0.009**	0.182	0.082	0.783*
	(0.003)	(1.270)	(1.316)	(1.846)	(0.004)	(0.158)	(0.185)	(0.432)
Δq^{Same}	0.290***	1.295***	1.918***	-0.336***	-0.007	0.788***	1.251***	2.410***
	(0.018)	(0.027)	(0.033)	(0.053)	(0.004)	(0.012)	(0.017)	(0.032)
$\Delta q^{Opposing}$	0.097***	0.086***	0.082***	0.057***	0.039***	0.071***	0.074***	0.081***
	(0.004)	(0.004)	(0.005)	(0.012)	(0.008)	(0.003)	(0.003)	(0.006)
Order Size	0.046***	-0.016***	-0.118***	0.298***	-0.407***	0.316***	0.245***	1.146***
	(0.004)	(0.004)	(0.005)	(0.014)	(0.009)	(0.003)	(0.003)	(0.006)
Fleeting Orders	0.702***	0.481***	0.342***	0.422***	0.617***	0.293***	0.293***	0.199***
	(0.004)	(0.004)	(0.005)	(0.013)	(0.008)	(0.003)	(0.003)	(0.005)
Spreads	0.062***	0.036***	0.035***	0.020	0.050***	0.003	0.001	0.010
	(0.004)	(0.005)	(0.005)	(0.016)	(0.009)	(0.003)	(0.004)	(0.008)
Volatility	0.099***	0.098***	0.117***	0.014	0.065***	0.064***	0.095***	-0.221***
	(0.004)	(0.005)	(0.005)	(0.016)	(0.009)	(0.003)	(0.004)	(0.008)
Market Depth	-0.208***	-0.278***	-0.330***	-0.264***	0.244***	-0.108***	-0.263***	-0.184***
	(0.004)	(0.004)	(0.005)	(0.012)	(0.009)	(0.003)	(0.004)	(0.006)
Lagged Duration					-0.014***	-0.001***	-0.001***	0.004***
					(<.001)	(<.001)	(<.001)	(<.001)
Constant	-0.629***	-1.287***	-1.725***	-3.924***	-2.322***	0.226***	-0.014***	-0.831***
	(0.006)	(0.006)	(0.007)	(0.018)	(0.013)	(0.004)	(0.005)	(0.008)
Unobhet	1.499***	1.380***	1.547***	3.183***	2.445***	0.262***	0.365***	0.684***
	(0.003)	(0.004)	(0.005)	(0.017)	(0.012)	(0.003)	(0.004)	(0.006)

Table 5.1 shows some interesting findings for dynamic limit order placement strategies in the pooled sample of buy limit orders in the ITS period. For limit orders originating from submission, the coefficient estimate of the initial aggressiveness measure, $p^{Relative}$, is found to be significantly positive for the destination state of order cancellation and significantly negative for the destination state of order revision. The estimates suggest that a higher initial aggressiveness of the submitted limit order tends to result in a higher hazard rate of order cancellation and a lower hazard rate of order revision. When a trader submits a limit order at an aggressive price, it indicates that the trader has a need for early execution of the order. For such limit orders, timing is important as they lie between the conventional limit orders which are patient and the market orders which require immediate execution. Therefore, when the market conditions change (e.g. liquidity is improved, spread is shortened), traders will have a tendency to cancel limit order and opt for market orders for an immediate execution. The intuition is consistent with the 'cost of immediacy hypothesis' and is evident in the estimation results, which suggest a higher probability of cancellation and a lower probability of revision for submitted limit orders with higher initial aggressiveness. On the other hand, when considering limit orders that originate from revision, the coefficient estimates of $p^{Relative}$ are positive and statistically significant for both destination states of order cancellation and order revision. The higher initial aggressiveness is, therefore, associated with a higher hazard rate for both cancellation and revision in this case. This positive relationship implies that after an aggressively submitted order is revised, there is a higher probability that it will be cancelled or it will continue to be revised if the stock market becomes more turbulent and moves away from the limit order's anticipated price range. Following the initial revisions, traders will continue to 'chase the market' by cancelling their existing order to submit another limit order; or they can simply revise the existing order with a more aggressive price. This result is, in fact, consistent with the 'chasing hypothesis' as described in the above section. The coefficient estimates of $p^{Relative}$ in *Table 5.2* for the sample of sell limit orders are generally not as statistically significant as those found in *Table 5.1* for the sample of buy limit orders. This outcome could be caused by the fact that the stock market was experiencing a bullish run in the period under study in this section. As a result, aggressive buy limit orders were a more dominating force in the stock market than aggressive sell limit orders.

The coefficient estimates of *Order Size* in both *Table 5.1* and *Table 5.2* show opposite effects which are all statistically significant for limit orders originating from submission compared to limit orders arising from revision in both samples of buy and sell limit orders. The size of the limit order is found to be positively (negatively) related to cancellation intensity and negatively (positively) related to revision intensity when the original state is an order submission (revision). This evidence supports the monitoring hypothesis of Liu (2009), which suggests that a limit order with a larger size tends to be monitored more closely than those with a smaller size. Specifically, a larger limit order could be associated with a larger opportunity cost. When the large limit order is submitted for the first time, it is more likely that early execution is preferred to minimise the waiting cost. Therefore, if better opportunity arrives, there is a higher tendency to cancel the limit order to opt for a market order for an immediate execution. On the other hand, when the larger order enters the origin state of revision, its waiting cost may not be as high as the one in submission state. As a result, the large limit order no longer requires urgent execution. Instead, the patient limit order will be monitored more closely and it will be revised, either more aggressively or more defensively, depending on the changes in the market conditions.

The results reported in *Table 5.1* and *Table 5.2* reconfirm the findings in the previous chapters regarding how market conditions affect dynamic limit order placement strategies. In both samples of buy and sell limit orders, the coefficient estimates of *Spreads* and *Volatility* are all positive and statistically significant, while the estimates for *Market Depth* are mostly negative and statistically significant. The coefficient estimates for *Fleeting Orders* are also significantly positive for both samples of buy and sell limit orders. When more fleeting orders appear in the market, they cause an increase in market turbulence. The results indicate that when the stock market experiences a higher level of short term volatility and a lower level of liquidity (larger spreads, lower depth), there is also a higher probability of order cancellation and revision activities. The effects are also found to be consistent when considering aggressive and defensive revisions. The lower quality market conditions stimulate limit order placement activities and as a response to such market conditions, traders intensify their actions for limit order cancellation and revision, including aggressive and defensive revisions. The findings of this section lend some support to the current literature. Ranaldo (2004) studies the order aggressiveness in limit order book markets and finds evidence for a higher level of aggressive trading activities when the spread is widened, when volatility is heightened, when the same side book is thicker or when the opposite side book is thinner. Similarly, Menkhoff et al. (2010) investigate the activities of limit order submission under asymmetric information and find that informed traders are more sensitive to changes in volatility, spreads, depth, and momentum.

Further evidence of the 'chasing hypothesis' is also found in the pooled sample of sell limit orders in this ITS period. The coefficient estimates of Δq^{Same} in *Table 5.2* are mostly positive and statistically significant. This result implies that when the best same-side quote moves adversely away from the initial best price, traders have a higher tendency to cancel their limit order and submit a more aggressive one; or they revise their limit order with a more aggressive price. By doing either way, the traders in fact 'chase the market' to gain better execution opportunities. This result is consistent with the 'chasing hypothesis' discussed by Hasbrouck and Saar (2009). Their study also finds evidence in favour of the 'cost of immediacy hypothesis' in the effects of the opposite quotes. The parameter estimates of $\Delta q^{Opposing}$ in this period are, however, mostly positive and significant for both samples of buy and sell limit orders. It implies that when the opposite quotes become cheaper, there is no evidence that traders are more motivated to cancel their existing limit orders in favour of market orders for executions against the more favourable bid (offer) quotes.

Moreover, *Table 5.1* and *Table 5.2* suggest that the time a limit order spends in the prior spells also has a negative impact on the probability of transition in the subsequent spell. The coefficient estimates for *Lagged Duration* are found to be negative and statistically significant across the two samples of buy and sell limit orders for both spell types, including revision-to-cancellation and revision-to-revision. This observation is in fact consistent with findings in the literature of labour economics. Studies, such as Van Ours (2004), conclude that if the subsidised job lasts too long, workers start reducing their job search intensity. As a direct comparison, the longer a limit order stays in the limit order book, the more discouraging it is for traders to search for better order placement strategies. Traders can either be extremely patient or they do not have a need for early execution. As a result, they may choose to set a limit price that is far away from the best quotes. This strategy, in turn, makes the limit order stay idle in the limit order book for an extended amount of time without being picked up or amended. Therefore, if the limit order has a longer duration in the previous spells, there is a lower probability that it will be revised or cancelled in the subsequent spell.

Negative duration dependence is also found in a number of multiple-spell duration analyses in the literature of economics (see, for example, Booth et al., 2002[16]; De Graaf-Zijl et al., 2011[17]). It is also interesting to observe that, even though coefficient estimates of *Lagged Duration* for aggressive revision are significantly negative, they are positive and significant for defensive revision. This result can be explained by an observation that the longer the limit order stays in the order book, the more likely it will continue staying there. Consequently, it is unlikely that the order will be revised more aggressively. In fact, if traders intend to amend such limit orders, it is more likely that they will take a defensive move.

Finally, the unobserved heterogeneity variable, *Unobhet*, is also included in the empirical model to represent the factors that could have an effect on the hazard rate of transitions for the limit order spells. These factors, however, are not observed and cannot be quantified. The coefficient estimates of *Unobhet* are positive and statistically significant across the two samples of buy and sell limit orders. They suggest a positive impact that the unobserved factors have on the probability of limit orders' transitions. Examples of such factors could include traders' preferences and trading objectives.

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[16] Booth et al. (2002) study the effect of the number of temporary contracts held in the past on current wages.

[17] De Graaf-Zijl et al. (2011) examine a multi-spell data for the labour market and conclude that temporary employment is a necessary path for a transition to a permanent job.

5.5.3. Integrated Trading System (ITS): Large Stocks vs Small Stocks

Survival analyses using the multiple-spell duration model are performed separately for large-cap and small-cap stocks in both samples of buy and sell limit orders in the ITS period. *Table 5.3* and *Table 5.4* show the empirical results for the low-latency multiple duration analysis of buy and sell limit orders, respectively, for the sample of large-capitalisation stocks. Similarly, *Table 5.5* and *Table 5.6* show the empirical results for the low-latency multiple duration analysis of buy and sell limit orders, respectively, for the sample of small-capitalisation stocks.

The results for both large-cap and small-cap stocks are generally consistent with the pooled sample and the parameter estimates can be interpreted in a similar way as discussed in the above section. Nevertheless, there are a couple of distinctions between the samples that represent the large-cap and small-cap stocks. Evidence of the 'cost of immediacy hypothesis' is found in the sample of large-cap stocks, as consistent with the pooled sample. However, in the sample of small-cap stocks, there is no evidence found that a higher initial aggressiveness leads to an increase in limit order cancellations to opt for market orders due to the 'cost of immediacy'. The coefficient estimate of $p^{Relative}$ is not statistically significant in the sample of buy limit orders and it is significantly negative in the sample of sell limit orders of small-cap stocks. Besides, submitting an aggressive limit order generally has a statistically insignificant effect on the hazard rate of limit order revisions, including aggressive and defensive revisions, in both samples of buy and sell limit orders of small-cap stocks.

Table 5.3: Low-Latency Multiple Duration Analysis of Buy Limit Orders of Large-Cap Stocks in the ITS Sample Period

This table presents the results for the multiple-spell duration analysis of buy limit orders in the sample of large stocks in the ITS period. The table describes the study of dynamic limit order placement strategies in a low-latency market environment. The estimation model used in this analysis is the Proportional Hazard model for multiple-spell duration. Definitions of the explanatory variables are given in the text. The coefficient estimates are presented for each of the variable and the standard errors are reported in the parentheses. ***, **, * denote statistical significance at the 1, 5 and 10 percent level respectively.

	Submission				Revision			
	Cancellation	*Revision*	*Aggressive Revision*	*Defensive Revision*	*Cancellation*	*Revision*	*Aggressive Revision*	*Defensive Revision*
$p^{Relative}$	0.159***	-0.021**	-0.081***	-0.003	0.175***	0.024***	0.001	0.029***
	(0.008)	(0.009)	(0.012)	(0.026)	(0.015)	(0.006)	(0.007)	(0.010)
Δq^{Same}	-0.222***	-0.007	0.056***	-0.097***	-0.182***	-0.064***	-0.040***	-0.117***
	(0.008)	(0.008)	(0.011)	(0.024)	(0.014)	(0.005)	(0.007)	(0.010)
$\Delta q^{Opposing}$	0.074***	0.826***	1.694***	-0.011	0.102***	0.836***	0.755***	1.138***
	(0.028)	(0.053)	(0.058)	(0.018)	(0.027)	(0.019)	(0.025)	(0.013)
Order Size	0.240***	-0.114***	-0.236***	0.266***	-0.347***	0.256***	0.165***	1.205***
	(0.005)	(0.004)	(0.005)	(0.015)	(0.009)	(0.003)	(0.003)	(0.007)
Fleeting Orders	0.682***	0.277***	0.162***	0.241***	0.512***	0.230***	0.228***	0.194***
	(0.005)	(0.004)	(0.005)	(0.014)	(0.009)	(0.003)	(0.003)	(0.006)
Spreads	0.032***	0.006	-0.002	0.054***	0.008	-0.005	-0.007*	-0.027***
	(0.005)	(0.005)	(0.006)	(0.015)	(0.010)	(0.003)	(0.004)	(0.009)
Volatility	0.130***	0.071***	0.068***	0.024	0.144***	0.051***	0.073***	-0.149***
	(0.005)	(0.005)	(0.006)	(0.017)	(0.010)	(0.003)	(0.004)	(0.009)
Market Depth	-0.039***	-0.233***	-0.340***	-0.254***	0.416***	-0.091***	-0.276***	-0.191***
	(0.005)	(0.004)	(0.005)	(0.014)	(0.009)	(0.003)	(0.004)	(0.006)
Lagged Duration					-0.012***	-0.001***	-0.001***	0.003***
					(<.001)	(<.001)	(<.001)	(<.001)
Constant	-0.604***	-1.023***	-1.310***	-3.809***	-2.636***	0.300***	0.083***	-0.703***
	(0.007)	(0.006)	(0.007)	(0.019)	(0.014)	(0.004)	(0.005)	(0.008)
Unobhet	1.816***	1.377***	1.529***	3.117***	2.305***	0.177***	0.233***	0.696***
	(0.004)	(0.004)	(0.005)	(0.016)	(0.016)	(0.003)	(0.004)	(0.006)

Table 5.4: Low-Latency Multiple Duration Analysis of Sell Limit Orders of Large-Cap Stocks in the ITS Sample Period

This table presents the results for the multiple-spell duration analysis of sell limit orders in the sample of large stocks in the ITS period. The table describes the study of dynamic limit order placement strategies in a low-latency market environment. The estimation model used in this analysis is the Proportional Hazard model for multiple-spell duration. Definitions of the explanatory variables are given in the text. The coefficient estimates are presented for each of the variable and the standard errors are reported in the parentheses. ***, **, * denote statistical significance at the 1, 5 and 10 percent level respectively.

	Submission				**Revision**			
	Cancellation	*Revision*	*Aggressive Revision*	*Defensive Revision*	*Cancellation*	*Revision*	*Aggressive Revision*	*Defensive Revision*
$p^{Relative}$	0.001	1.048**	0.418**	1.559***	-0.009*	0.164	0.031	0.994*
	(0.003)	(0.505)	(0.207)	(0.976)	(0.005)	(0.177)	(0.204)	(0.522)
Δq^{Same}	0.425***	2.057***	2.812***	-0.223***	-0.008*	1.396***	1.936***	4.612***
	(0.028)	(0.045)	(0.051)	(0.044)	(0.005)	(0.019)	(0.027)	(0.048)
$\Delta q^{Opposing}$	0.102***	0.095***	0.093***	0.054***	0.046***	0.077***	0.080***	0.078***
	(0.005)	(0.005)	(0.005)	(0.013)	(0.008)	(0.003)	(0.003)	(0.007)
Order Size	0.102***	-0.119***	-0.234***	0.229***	-0.319***	0.271***	0.186***	1.193***
	(0.005)	(0.004)	(0.005)	(0.014)	(0.009)	(0.003)	(0.003)	(0.007)
Fleeting Orders	0.675***	0.373***	0.220***	0.310***	0.592***	0.239***	0.234***	0.149***
	(0.004)	(0.004)	(0.005)	(0.014)	(0.008)	(0.003)	(0.003)	(0.006)
Spreads	0.075***	0.027***	0.024***	0.011	0.052***	-0.002	-0.005	0.004
	(0.005)	(0.005)	(0.006)	(0.018)	(0.010)	(0.003)	(0.004)	(0.009)
Volatility	0.148***	0.069***	0.077***	-0.003	0.084***	0.061***	0.090***	-0.199***
	(0.005)	(0.005)	(0.006)	(0.017)	(0.010)	(0.003)	(0.004)	(0.009)
Market Depth	-0.182***	-0.283***	-0.341***	-0.254***	0.270***	-0.093***	-0.252***	-0.152***
	(0.005)	(0.004)	(0.005)	(0.013)	(0.010)	(0.003)	(0.004)	(0.006)
Lagged Duration					-0.014***	-0.001***	-0.001***	0.003***
					(<.001)	(<.001)	(<.001)	(<.001)
Constant	-0.586***	-1.037***	-1.457***	-3.693***	-2.355***	0.312***	0.085***	-0.767***
	(0.007)	(0.006)	(0.007)	(0.020)	(0.014)	(0.004)	(0.005)	(0.008)
Unobhet	1.666***	1.261***	1.411***	2.989***	2.404***	0.186***	0.275***	0.589***
	(0.004)	(0.005)	(0.006)	(0.019)	(0.014)	(0.003)	(0.004)	(0.006)

Table 5.5: Low-Latency Multiple Duration Analysis of Buy Limit Orders of Small-Cap Stocks in the ITS Sample Period

This table presents the results for the multiple-spell duration analysis of buy limit orders in the sample of small stocks in the ITS period. The table describes the study of dynamic limit order placement strategies in a low-latency market environment. The estimation model used in this analysis is the Proportional Hazard model for multiple-spell duration. Definitions of the explanatory variables are given in the text. The coefficient estimates are presented for each of the variable and the standard errors are reported in the parentheses. ***, **, * denote statistical significance at the 1, 5 and 10 percent level respectively.

	Submission				**Revision**			
	Cancellation	*Revision*	*Aggressive Revision*	*Defensive Revision*	*Cancellation*	*Revision*	*Aggressive Revision*	*Defensive Revision*
$p^{Relative}$	0.001	-0.026*	-0.075***	0.148***	0.019	0.008	0.007	-0.015
	(0.011)	(0.015)	(0.018)	(0.037)	(0.027)	(0.011)	(0.014)	(0.019)
Δq^{Same}	-0.052***	0.011	0.056***	-0.211***	0.008	-0.055***	-0.045***	-0.086***
	(0.010)	(0.013)	(0.016)	(0.052)	(0.023)	(0.010)	(0.012)	(0.019)
$\Delta q^{Opposing}$	0.109***	0.471***	0.669***	-0.315***	0.089***	0.187***	0.296***	0.561***
	(0.012)	(0.013)	(0.016)	(0.054)	(0.018)	(0.008)	(0.010)	(0.017)
Order Size	0.192***	-0.236***	-0.326***	0.047	-0.752***	0.432***	0.367***	1.527***
	(0.008)	(0.009)	(0.010)	(0.035)	(0.022)	(0.008)	(0.010)	(0.020)
Fleeting Orders	0.885***	0.442***	0.320***	0.341***	0.435***	0.522***	0.547***	0.571***
	(0.009)	(0.013)	(0.015)	(0.047)	(0.025)	(0.008)	(0.010)	(0.015)
Spreads	-0.034***	0.003	-0.003	0.068*	0.019	0.021***	0.014	0.032**
	(0.008)	(0.011)	(0.012)	(0.037)	(0.024)	(0.008)	(0.010)	(0.014)
Volatility	0.111***	0.036***	0.057***	-0.021	0.020	-0.006	0.006	-0.055***
	(0.008)	(0.011)	(0.012)	(0.040)	(0.022)	(0.008)	(0.010)	(0.014)
Market Depth	-0.460***	-0.322***	-0.299***	-0.475***	-0.008	-0.445***	-0.530***	-0.594***
	(0.007)	(0.009)	(0.011)	(0.035)	(0.020)	(0.007)	(0.010)	(0.015)
Lagged Duration					-0.007***	0.002***	0.003***	0.005***
					(<.001)	(<.001)	(<.001)	(<.001)
Constant	-0.862***	-2.354***	-2.859***	-4.390***	-2.921***	-0.280***	-0.674***	-1.142***
	(0.009)	(0.011)	(0.013)	(0.046)	(0.030)	(0.010)	(0.012)	(0.020)
Unobhet	1.173***	1.333***	1.455***	3.858***	2.299***	0.478***	0.590***	0.998***
	(0.006)	(0.012)	(0.015)	(0.043)	(0.031)	(0.007)	(0.010)	(0.012)

Table 5.6: Low-Latency Multiple Duration Analysis of Sell Limit Orders of Small-Cap Stocks in the ITS Sample Period

This table presents the results for the multiple-spell duration analysis of sell limit orders in the sample of small stocks in the ITS period. The table describes the study of dynamic limit order placement strategies in a low-latency market environment. The estimation model used in this analysis is the Proportional Hazard model for multiple-spell duration. Definitions of the explanatory variables are given in the text. The coefficient estimates are presented for each of the variable and the standard errors are reported in the parentheses. ***, **, * denote statistical significance at the 1, 5 and 10 percent level respectively.

	Submission				**Revision**			
	Cancellation	*Revision*	*Aggressive Revision*	*Defensive Revision*	*Cancellation*	*Revision*	*Aggressive Revision*	*Defensive Revision*
$p^{Relative}$	-0.011**	-0.004	-0.006	-0.002	-0.013**	-0.141	-0.011	0.017
	(0.005)	(0.014)	(0.015)	(0.074)	(0.005)	(0.175)	(0.033)	(0.014)
Δq^{Same}	-0.012	0.562***	0.815***	-0.579***	0.061***	0.259***	0.522***	0.375***
	(0.008)	(0.013)	(0.016)	(0.047)	(0.010)	(0.008)	(0.011)	(0.016)
$\Delta q^{Opposing}$	0.074***	0.032***	0.037***	0.065**	-0.001	0.052***	0.054***	0.061***
	(0.007)	(0.010)	(0.012)	(0.033)	(0.010)	(0.007)	(0.010)	(0.016)
Order Size	0.127***	-0.136***	-0.286***	-0.078**	-0.327***	0.418***	0.355***	1.377***
	(0.008)	(0.009)	(0.011)	(0.036)	(0.015)	(0.008)	(0.010)	(0.020)
Fleeting Orders	0.859***	0.596***	0.386***	0.576***	0.423***	0.465***	0.462***	0.514***
	(0.008)	(0.012)	(0.015)	(0.042)	(0.015)	(0.008)	(0.010)	(0.015)
Spreads	-0.001	-0.049***	-0.067***	0.032	-0.001	0.023***	0.016	0.023
	(0.007)	(0.011)	(0.014)	(0.042)	(0.012)	(0.008)	(0.010)	(0.017)
Volatility	0.121***	0.091***	0.109***	-0.037	0.076***	0.092***	0.103***	0.068***
	(0.007)	(0.011)	(0.013)	(0.040)	(0.012)	(0.008)	(0.010)	(0.016)
Market Depth	-0.385***	-0.429***	-0.388***	-0.726***	-0.106***	-0.404***	-0.529***	-0.501***
	(0.007)	(0.010)	(0.012)	(0.038)	(0.013)	(0.008)	(0.010)	(0.016)
Lagged Duration					-0.008***	0.002***	0.004***	0.005***
					(<.001)	(<.001)	(<.001)	(<.001)
Constant	-0.702***	-2.314***	-2.975***	-4.455***	-2.701***	-0.247***	-0.680***	-1.171***
	(0.009)	(0.012)	(0.014)	(0.046)	(0.019)	(0.011)	(0.013)	(0.021)
Unobhet	1.104***	1.393***	1.476***	3.851***	0.409***	0.477***	0.589***	1.003***
	(0.006)	(0.012)	(0.015)	(0.045)	(0.134)	(0.008)	(0.010)	(0.013)

The effects of market conditions on the intensity of order placement activities for both large and small stocks are generally consistent with the pooled sample in this period. Specifically, when market quality declines due to higher turbulence, higher short term volatility and lower liquidity, traders respond by intensifying their order activities, including order cancellation and order revision. This effect is shown by the significantly positive coefficient estimates of *Fleeting Orders*, *Spreads* and *Volatility*; as well as by the mostly negative and significant coefficient estimates of *Market Depth*. There is, however, one exception in the case of small-cap stocks where the parameter estimates for *Spreads* are generally negative and statistically significant for buy and sell limit orders that originate from submission. It indicates that, in this period, traders of small-cap stocks do not respond to changes in the spreads in the same way as they do for the large-cap stocks. In other words, traders submitting limit orders to buy or sell small-cap stocks concern more about the stock market with a lower level of liquidity caused by a reduced level of depth than one caused by the widening of spreads.

Furthermore, there is another noticeable distinction in the sample of small-cap stocks compared to the sample of large-cap stocks or the pooled sample in this ITS period. The coefficient estimates of duration dependence variable, *Lagged Duration*, in the sample of large-cap stocks are consistent with the pooled sample, i.e. they are negative and significant for all destination states, except for defensive revision. The sample of small-cap stocks, however, show significantly negative estimates only for the destination state of cancellation. The rest of the destination states reveal significantly positive coefficient estimates of *Lagged Duration*. In other words, all destination states of revisions, including aggressive and defensive revisions, experience positive and significant duration dependence in the both samples of buy and sell limit orders for the small-cap stocks. These results seem to suggest that revision activities of small-cap stocks are more intense at the low-latency level than large-cap stocks. Traders of smaller stocks can be more patient since the cost of waiting for them is not as high as the larger stocks. Therefore, spending a longer time in the previous spells does not prevent traders of small-cap stocks intensifying their revision activities (both aggressive and defensive). This intensity of revision activities for small stocks could also be a part of dynamic order placement strategies conducted by high-frequency traders who utilise the benefit of a low-latency market environment.

5.5.4. The Pooled Sample of Buy and Sell Limit Orders in the ASX Trade Period

In November 2010, ASX launched its new trading platform, called the ASX Trade. This structural change with new technological improvements helped reduce the market latency even further. The results of survival analyses utilising a multiple-spell duration model are presented in *Table 5.7* and *Table 5.8* for the pooled sample of buy and sell limit orders, respectively. Each result table is, again, divided into two sections associated with the *origin states* of order submission and order revision. The parameter estimates and their levels of significance are then reported for each variable in the model for each *destination state*. The *destination states* include order cancellation, order revision, aggressive revision and defensive revision. The standard errors are also included in the parentheses.

Table 5.7: ASX Trade Period and Low-Latency Multiple Duration Analysis of Buy Limit Orders in the Pooled Sample

This table presents the results for the ASX Trade period with multiple-spell duration analysis of buy limit orders in the pooled sample. The table describes the study of dynamic limit order placement strategies in a low-latency market environment. The estimation model used in this analysis is the Proportional Hazard model for multiple-spell duration. Definitions of the explanatory variables are given in the text. The coefficient estimates are presented for each of the variable and the standard errors are reported in the parentheses. ***, **, * denote statistical significance at the 1, 5 and 10 percent level respectively.

	Submission				**Revision**			
	Cancellation	*Revision*	*Aggressive Revision*	*Defensive Revision*	*Cancellation*	*Revision*	*Aggressive Revision*	*Defensive Revision*
$p^{Relative}$	0.082***	0.027***	-0.019***	0.085***	0.087***	0.030***	0.030***	-0.001
	(0.002)	(0.004)	(0.006)	(0.018)	(0.005)	(0.003)	(0.005)	(0.003)
Δq^{Same}	-0.115***	-0.084***	-0.006	-0.297***	-0.074***	-0.102***	-0.093***	-0.068***
	(0.002)	(0.004)	(0.005)	(0.020)	(0.004)	(0.003)	(0.005)	(0.003)
$\Delta q^{Opposing}$	-0.019***	0.231***	0.796***	-0.760***	0.040***	-0.132***	-0.018**	0.103***
	(0.003)	(0.010)	(0.011)	(0.052)	(0.010)	(0.009)	(0.008)	(0.006)
Order Size	0.156***	-0.192***	-0.607***	0.305***	-0.611***	1.084***	1.471***	0.830***
	(0.002)	(0.003)	(0.004)	(0.015)	(0.005)	(0.003)	(0.004)	(0.003)
Fleeting Orders	0.357***	0.875***	0.769***	1.389***	0.750***	0.434***	0.528***	0.266***
	(0.001)	(0.002)	(0.003)	(0.009)	(0.003)	(0.002)	(0.003)	(0.002)
Spreads	-0.012***	0.026***	0.014***	-0.006	0.023***	0.012***	-0.043***	-0.023***
	(0.002)	(0.004)	(0.004)	(0.016)	(0.005)	(0.002)	(0.004)	(0.002)
Volatility	0.048***	0.088***	0.147***	0.211***	-0.040***	0.209***	0.269***	0.099***
	(0.002)	(0.003)	(0.004)	(0.015)	(0.005)	(0.003)	(0.004)	(0.002)
Market Depth	-0.017***	-0.053***	-0.083***	0.023*	0.084***	-0.134***	-0.255***	-0.229***
	(0.002)	(0.003)	(0.004)	(0.014)	(0.004)	(0.002)	(0.005)	(0.005)
Lagged Duration					-0.057***	-0.011***	-0.009***	-0.001***
					(<.001)	(<.001)	(<.001)	(<.001)
Constant	-0.094***	-2.965***	-3.893***	-5.671***	-2.212***	2.477***	1.259***	-1.132***
	(0.005)	(0.009)	(0.011)	(0.040)	(0.015)	(0.009)	(0.015)	(0.007)
Unobhet	0.862***	1.932***	2.107***	4.778***	2.079***	1.278***	1.513***	-1.006***
	(0.002)	(0.003)	(0.004)	(0.007)	(0.005)	(0.001)	(0.002)	(0.017)

Table 5.8: ASX Trade Period and Low-Latency Multiple Duration Analysis of Sell Limit Orders in the Pooled Sample

This table presents the results for the ASX Trade period with multiple-spell duration analysis of sell limit orders in the pooled sample. The table describes the study of dynamic limit order placement strategies in a low-latency market environment. The estimation model used in this analysis is the Proportional Hazard model for multiple-spell duration. Definitions of the explanatory variables are given in the text. The coefficient estimates are presented for each of the variable and the standard errors are reported in the parentheses. ***, **, * denote statistical significance at the 1, 5 and 10 percent level respectively.

	Submission				Revision			
	Cancellation	*Revision*	*Aggressive Revision*	*Defensive Revision*	*Cancellation*	*Revision*	*Aggressive Revision*	*Defensive Revision*
$p^{Relative}$	0.002	-0.004**	-0.375***	1.039***	-0.661***	-0.741***	-0.766***	0.863***
	(0.002)	(0.002)	(0.073)	(0.209)	(0.006)	(0.008)	(0.018)	(0.012)
Δq^{Same}	-0.735***	0.308***	1.217***	-1.478***	0.110***	0.053***	0.504***	1.397***
	(0.003)	(0.005)	(0.013)	(0.064)	(0.003)	(0.008)	(0.010)	(0.016)
$\Delta q^{Opposing}$	0.067***	0.065***	0.114***	0.156***	0.018***	0.111***	0.118***	0.132***
	(0.002)	(0.002)	(0.004)	(0.013)	(0.002)	(0.002)	(0.004)	(0.005)
Order Size	0.018***	-0.325***	-0.764***	0.194***	-0.336***	1.315***	1.495***	2.380***
	(0.002)	(0.002)	(0.004)	(0.015)	(0.002)	(0.003)	(0.004)	(0.006)
Fleeting Orders	0.366***	0.528***	0.792***	1.392***	0.386***	0.083***	0.583***	0.329***
	(0.001)	(0.001)	(0.002)	(0.009)	(0.002)	(0.002)	(0.003)	(0.004)
Spreads	0.013***	0.027***	0.045***	0.099***	0.022***	-0.042***	-0.003	0.013***
	(0.002)	(0.002)	(0.004)	(0.015)	(0.002)	(0.003)	(0.004)	(0.005)
Volatility	0.064***	0.047***	0.134***	0.137***	0.014***	0.202***	0.211***	0.171***
	(0.002)	(0.002)	(0.004)	(0.015)	(0.002)	(0.003)	(0.004)	(0.005)
Market Depth	-0.029***	-0.046***	-0.070***	-0.120***	0.028***	0.123***	-0.268***	-0.355***
	(0.002)	(0.002)	(0.004)	(0.014)	(0.002)	(0.003)	(0.005)	(0.007)
Lagged Duration					-0.054***	-0.015***	-0.011***	-0.008***
					(<.001)	(<.001)	(<.001)	(<.001)
Constant	0.020***	-2.836***	-3.755***	-5.551***	-2.427***	4.462***	0.932***	2.519***
	(0.005)	(0.005)	(0.010)	(0.042)	(0.009)	(0.008)	(0.015)	(0.021)
Unobhet	0.555***	0.302***	1.928***	4.711***	-0.229***	1.378***	1.482***	1.875***
	(0.002)	(0.008)	(0.004)	(0.007)	(0.012)	(0.001)	(0.002)	(0.002)

One of the most noticeable distinctions between the two sample periods of ITS and ASX Trade is the effect of initial aggressiveness level on the hazard rate of order revision. For buy limit orders of the ASX Trade sample period, *Table 5.7* shows a positive and significant coefficient estimate of $p^{Relative}$ for order revision originating from submission. The same estimate is, however, found to be significantly negative in the ITS period, as seen in *Table 5.1*. Similarly, for sell limit orders of the ASX Trade sample period, *Table 5.8* shows a significantly negative coefficient estimate of $p^{Relative}$ for order revision originating from submission. *Table 5.2*, however, finds the same estimate to be positive and statistically significant in the ITS period. The results indicate that in the ASX Trade period, a higher level of initial aggressiveness tends to increase (decrease) the probability of revision following the submission of the order for buy (sell) limit orders. The effects of initial aggressiveness are also more statistically significant in this period than the previous period of ITS, especially for the revision-to-revision order spells in the sample of sell limit orders. The evidence seems to suggest that the decision to submit a more aggressive limit order in this period has a more significant impact on the intensity of cancellation and revision activities conducted by traders. This effect could partially be contributed by the fact that ASX Trade significantly reduced the market latency even further than ITS.

Another distinction of the ASX Trade period can be found in the effects of changes in the opposite quotes. Specifically, *Table 5.7* shows that the coefficient estimate of $\Delta q^{Opposing}$ is negative and statistically significant for destination state of order cancellation which originates from submission of buy limit orders. It indicates that when the opposite quotes become cheaper, traders are more motivated to cancel their existing limit orders in favour of market orders for an immediate execution. This finding is in fact consistent with the 'cost of immediacy hypothesis' discussed in Hasbrouck and

Saar (2009). Evidence consistent with this hypothesis can be found if there is an increase in the probability of rapid cancellation of limit orders when the opposite side of the best bid or offer approaches the limit price after the order is placed in the book.

Unlike the previous period of ITS, this ASX Trade sample period shows a coefficient estimate of Δq^{Same} that is negative and statistically significant for order cancellation originating from submission of sell limit orders (as evident in *Table 5.8*). Hasbrouck and Saar (2009) show that when the market moves away from traders' submitted limit orders, they would 'chase the market' by cancelling stale orders and resubmitting more aggressive ones. Their study, however, is based on a stock market where traders cannot revise their limit orders. In this research of the ASX Trade, even though traders reduce their cancellation activities when the best same-side quote moves adversely away from the initial best price (i.e. a higher value of Δq^{Same}), they at the same time increase their activities in limit order revision. This action is evident in the sample of sell limit orders (*Table 5.8*) where the coefficient estimate of Δq^{Same} is significantly positive for order revision originating from submission. Traders, therefore, respond to the changes in same-side quotes by revising their limit orders with more aggressive ones in order to gain better execution opportunities. The combined effect is, indeed, still consistent with the 'chasing hypothesis' discussed in Hasbrouck and Saar (2009).

Finally, the rest of the results in this period are generally consistent with the prior period. Specifically, most of the quality measures of the stock market in the period of ASX Trade appear to have consistent effects with the ITS period on the intensity of order cancellation and order revision activities. Particularly, traders in this period also respond to a drop in market quality by increasing their order placement activities. *Table 5.7* and *Table 5.8* show generally positive and significant estimates for the coefficients of *Volatility* and *Fleeting Orders*. The coefficient estimates of *Market Depth* are also mostly negative and statistically significant as found in the previous period. Nevertheless, a number of limit order spells in this ASX Trade period experience mixed effects when *Spreads* is considered as a measure for market quality. The parameter estimates for *Spreads* are positive and statistically significant in most cases. They are, however, significantly negative in some other cases (e.g. for order spell type submission-to-cancellation in the sample of buy limit orders and for order spell type revision-to-revision in the sample of sell limit orders). This observation tends to suggest that even though traders of ASX Trade period also act upon a higher turbulence, a higher short term volatility and a lower liquidity level in the same way as the prior period, they do not respond to the changes of the quoted spreads in the same way as previously. The results, in fact, lend some support for the study conducted by Liu (2009) which finds that traders cancel or revise their limit orders to eliminate the 'free-option risk' in volatile periods.

5.5.5. The Samples of Large Stocks and Small Stocks in the ASX Trade Period

For completeness, survival analyses utilising the multiple-spell duration model are also conducted separately for both samples of large-cap and small-cap stocks for both buy and sell limit orders in the ASX Trade period. *Table 5.9* and *Table 5.10* show the empirical results for the low-latency multiple duration analysis of buy and sell limit orders, respectively, for the large-cap stocks. Similarly, *Table 5.11* and *Table 5.12* show the empirical results for the low-latency multiple duration analysis of buy and sell limit orders, respectively, for the small-cap stocks.

Table 5.9: ASX Trade Period and Low-Latency Multiple Duration Analysis of Buy Limit Orders of Large-Cap Stocks

This table presents the results for the ASX Trade period with multiple-spell duration analysis of buy limit orders in the sample of large-cap stocks. The table describes the study of dynamic limit order placement strategies in a low-latency market environment. The estimation model used in this analysis is the Proportional Hazard model for multiple-spell duration. Definitions of the explanatory variables are given in the text. The coefficient estimates are presented for each of the variable and the standard errors are reported in the parentheses. ***, **, * denote statistical significance at the 1, 5 and 10 percent level respectively.

	Submission				Revision			
	Cancellation	*Revision*	*Aggressive Revision*	*Defensive Revision*	*Cancellation*	*Revision*	*Aggressive Revision*	*Defensive Revision*
$p^{Relative}$	0.097***	0.033***	-0.016**	0.035	0.089***	0.030***	-0.003	0.012***
	(0.003)	(0.005)	(0.007)	(0.022)	(0.005)	(0.003)	(0.006)	(0.002)
Δq^{Same}	-0.130***	-0.100***	-0.020***	-0.282***	-0.074***	-0.104***	-0.075***	-0.064***
	(0.003)	(0.004)	(0.006)	(0.023)	(0.005)	(0.003)	(0.005)	(0.002)
$\Delta q^{Opposing}$	-0.009***	0.055***	1.306***	-0.770***	0.003	-0.242***	-0.494***	0.295***
	(0.003)	(0.011)	(0.021)	(0.126)	(0.005)	(0.017)	(0.024)	(0.009)
Order Size	0.177***	-0.155***	-0.605***	0.382***	-0.484***	1.062***	1.478***	0.495***
	(0.002)	(0.003)	(0.004)	(0.017)	(0.005)	(0.003)	(0.004)	(0.002)
Fleeting Orders	0.445***	0.816***	0.639***	1.373***	0.765***	0.459***	0.480***	0.270***
	(0.002)	(0.003)	(0.004)	(0.014)	(0.004)	(0.002)	(0.004)	(0.002)
Spreads	-0.008***	0.025***	0.005	-0.010	0.023***	0.015***	-0.044***	-0.002
	(0.003)	(0.004)	(0.005)	(0.018)	(0.006)	(0.002)	(0.004)	(0.002)
Volatility	0.046***	0.084***	0.159***	0.218***	-0.053***	0.218***	0.275***	0.072***
	(0.003)	(0.004)	(0.005)	(0.017)	(0.005)	(0.003)	(0.004)	(0.002)
Market Depth	-0.009***	-0.099***	-0.157***	-0.022	0.077***	-0.124***	-0.257***	-0.087***
	(0.002)	(0.004)	(0.005)	(0.016)	(0.004)	(0.002)	(0.005)	(0.002)
Lagged Duration					-0.073***	-0.013***	-0.012***	-0.002***
					(0.001)	(<.001)	(<.001)	(<.001)
Constant	-0.410***	-2.648***	-3.332***	-5.383***	-2.323***	2.502***	1.746***	-0.593***
	(0.008)	(0.014)	(0.017)	(0.070)	(0.021)	(0.013)	(0.020)	(0.008)
Unobhet	0.960***	1.931***	2.091***	4.796***	2.043***	1.290***	1.534***	-0.777***
	(0.002)	(0.003)	(0.005)	(0.008)	(0.005)	(0.002)	(0.002)	(0.011)

Table 5.10: ASX Trade Period and Low-Latency Multiple Duration Analysis of Sell Limit Orders of Large-Cap Stocks

This table presents the results for the ASX Trade period with multiple-spell duration analysis of sell limit orders in the sample of large-cap stocks. The table describes the study of dynamic limit order placement strategies in a low-latency market environment. The estimation model used in this analysis is the Proportional Hazard model for multiple-spell duration. Definitions of the explanatory variables are given in the text. The coefficient estimates are presented for each of the variable and the standard errors are reported in the parentheses. ***, **, * denote statistical significance at the 1, 5 and 10 percent level respectively.

	Submission				**Revision**			
	Cancellation	*Revision*	*Aggressive Revision*	*Defensive Revision*	*Cancellation*	*Revision*	*Aggressive Revision*	*Defensive Revision*
$p^{Relative}$	0.010	-0.027***	-0.435***	0.906***	-0.826***	-0.685***	0.011***	-0.192***
	(0.007)	(0.008)	(0.131)	(0.074)	(0.006)	(0.008)	(0.003)	(0.004)
Δq^{Same}	0.159***	0.480***	2.502***	-2.396***	3.608***	0.067***	0.348***	2.553***
	(0.004)	(0.008)	(0.041)	(0.157)	(0.024)	(0.007)	(0.019)	(0.017)
$\Delta q^{Opposing}$	0.036***	0.067***	0.075***	0.172***	0.079***	0.108***	0.123***	0.119***
	(0.001)	(0.002)	(0.004)	(0.016)	(0.005)	(0.002)	(0.004)	(0.004)
Order Size	0.138***	-0.324***	-0.122***	0.319***	0.130***	1.067***	1.519***	1.351***
	(0.001)	(0.002)	(0.003)	(0.017)	(0.005)	(0.003)	(0.004)	(0.004)
Fleeting Orders	0.201***	0.443***	0.410***	1.280***	0.821***	0.445***	0.467***	0.469***
	(0.001)	(0.002)	(0.003)	(0.014)	(0.004)	(0.002)	(0.004)	(0.004)
Spreads	0.009***	0.024***	0.022***	0.116***	0.031***	-0.015***	-0.004	-0.029***
	(0.002)	(0.002)	(0.004)	(0.018)	(0.005)	(0.003)	(0.004)	(0.004)
Volatility	0.029***	0.048***	0.085***	0.130***	0.002	0.178***	0.210***	0.156***
	(0.001)	(0.002)	(0.003)	(0.017)	(0.005)	(0.003)	(0.004)	(0.004)
Market Depth	-0.066***	-0.061***	-0.131***	-0.144***	-0.058***	-0.127***	-0.234***	-0.164***
	(0.001)	(0.002)	(0.004)	(0.016)	(0.005)	(0.003)	(0.005)	(0.004)
Lagged Duration					-0.027***	-0.015***	-0.013***	-0.011***
					(0.001)	(<.001)	(<.001)	(<.001)
Constant	-0.805***	-2.500***	-2.205***	-4.770***	-1.476***	2.605***	1.777***	2.483***
	(0.005)	(0.008)	(0.013)	(0.071)	(0.020)	(0.012)	(0.020)	(0.019)
Unobhet	-0.858***	0.173***	0.172***	4.750***	0.962***	1.287***	1.515***	1.637***
	(0.007)	(0.009)	(0.009)	(0.008)	(0.004)	(0.002)	(0.002)	(0.002)

Table 5.11: ASX Trade Period and Low-Latency Multiple Duration Analysis of Buy Limit Orders of Small-Cap Stocks

This table presents the results for the ASX Trade period with multiple-spell duration analysis of buy limit orders in the sample of small-cap stocks. The table describes the study of dynamic limit order placement strategies in a low-latency market environment. The estimation model used in this analysis is the Proportional Hazard model for multiple-spell duration. Definitions of the explanatory variables are given in the text. The coefficient estimates are presented for each of the variable and the standard errors are reported in the parentheses. ***, **, * denote statistical significance at the 1, 5 and 10 percent level respectively.

	Submission				**Revision**			
	Cancellation	*Revision*	*Aggressive Revision*	*Defensive Revision*	*Cancellation*	*Revision*	*Aggressive Revision*	*Defensive Revision*
$p^{Relative}$	0.057***	-0.005	-0.016	0.010	0.032**	0.045***	0.144***	0.048***
	(0.004)	(0.009)	(0.012)	(0.015)	(0.014)	(0.008)	(0.013)	(0.008)
Δq^{Same}	-0.087***	-0.025***	0.025***	-0.129***	-0.053***	-0.074***	-0.104***	-0.049***
	(0.004)	(0.007)	(0.009)	(0.015)	(0.012)	(0.007)	(0.011)	(0.009)
$\Delta q^{Opposing}$	-0.052***	0.255***	0.463***	-0.056***	0.137***	-0.071***	0.289***	0.090***
	(0.004)	(0.008)	(0.009)	(0.017)	(0.014)	(0.010)	(0.012)	(0.006)
Order Size	0.103***	-0.478***	-0.667***	-0.051***	-1.348***	0.842***	0.644***	0.737***
	(0.003)	(0.006)	(0.008)	(0.012)	(0.013)	(0.008)	(0.011)	(0.010)
Fleeting Orders	0.292***	0.456***	0.425***	0.500***	0.339***	0.331***	0.216***	0.078***
	(0.003)	(0.005)	(0.007)	(0.010)	(0.012)	(0.006)	(0.008)	(0.006)
Spreads	-0.012***	-0.030***	-0.037***	-0.004	0.032**	-0.055***	-0.029**	-0.013
	(0.004)	(0.007)	(0.010)	(0.013)	(0.014)	(0.008)	(0.012)	(0.010)
Volatility	0.033***	0.177***	0.118***	0.224***	0.150***	0.010	0.052***	-0.013
	(0.004)	(0.007)	(0.009)	(0.013)	(0.013)	(0.008)	(0.011)	(0.008)
Market Depth	-0.004	-0.007	-0.009	-0.003	0.050***	-0.175***	-0.305***	-0.262***
	(0.003)	(0.006)	(0.009)	(0.011)	(0.012)	(0.007)	(0.014)	(0.014)
Lagged Duration					-0.023***	-0.005***	0.003***	0.003***
					(0.001)	(<.001)	(<.001)	(<.001)
Constant	-0.147***	-2.539***	-3.429***	-3.400***	-1.224***	1.600***	-0.218***	-1.501***
	(0.006)	(0.012)	(0.015)	(0.024)	(0.030)	(0.015)	(0.021)	(0.014)
Unobhet	0.633***	1.816***	1.995***	3.100***	2.224***	1.150***	1.182***	-1.155***
	(0.003)	(0.008)	(0.011)	(0.014)	(0.012)	(0.005)	(0.009)	(0.070)

Table 5.12: ASX Trade Period and Low-Latency Multiple Duration Analysis of Sell Limit Orders of Small-Cap Stocks

This table presents the results for the ASX Trade period with multiple-spell duration analysis of sell limit orders in the sample of small-cap stocks. The table describes the study of dynamic limit order placement strategies in a low-latency market environment. The estimation model used in this analysis is the Proportional Hazard model for multiple-spell duration. Definitions of the explanatory variables are given in the text. The coefficient estimates are presented for each of the variable and the standard errors are reported in the parentheses. ***, **, * denote statistical significance at the 1, 5 and 10 percent level respectively.

	Submission				Revision			
	Cancellation	*Revision*	*Aggressive Revision*	*Defensive Revision*	*Cancellation*	*Revision*	*Aggressive Revision*	*Defensive Revision*
$p^{Relative}$	-0.003*	-0.007	-0.012*	-0.005	-1.006***	-1.402***	-1.021***	-0.520***
	(0.002)	(0.006)	(0.007)	(0.018)	(0.016)	(0.018)	(0.013)	(0.030)
Δq^{Same}	0.001	-0.137***	0.110***	-0.318***	0.146***	0.123***	0.649***	0.698***
	(0.002)	(0.006)	(0.006)	(0.019)	(0.006)	(0.014)	(0.012)	(0.019)
$\Delta q^{Opposing}$	0.030***	0.078***	0.054***	0.045***	0.024***	0.071***	0.073***	0.079***
	(0.002)	(0.006)	(0.007)	(0.017)	(0.006)	(0.007)	(0.010)	(0.017)
Order Size	0.020***	-0.521***	-0.592***	-0.234***	-0.395***	1.606***	0.510***	1.393***
	(0.002)	(0.006)	(0.007)	(0.016)	(0.007)	(0.008)	(0.010)	(0.018)
Fleeting Orders	0.167***	0.515***	0.417***	0.458***	0.221***	-0.226***	0.318***	0.222***
	(0.002)	(0.005)	(0.006)	(0.016)	(0.006)	(0.005)	(0.008)	(0.014)
Spreads	0.009***	-0.027***	-0.031***	0.007	-0.007	-0.078***	0.018	0.053***
	(0.002)	(0.007)	(0.008)	(0.019)	(0.007)	(0.008)	(0.011)	(0.020)
Volatility	0.019***	0.103***	0.105***	0.041**	0.045***	-0.065***	0.090***	0.040**
	(0.002)	(0.006)	(0.006)	(0.018)	(0.007)	(0.007)	(0.010)	(0.018)
Market Depth	-0.078***	-0.052***	-0.111***	-0.090***	-0.017**	1.073***	-0.469***	-0.470***
	(0.002)	(0.006)	(0.008)	(0.021)	(0.008)	(0.034)	(0.014)	(0.024)
Lagged Duration					-0.028***	-0.008***	0.004***	0.010***
					(0.001)	(<.001)	(<.001)	(<.001)
Constant	-0.677***	-2.370***	-3.173***	-5.261***	-1.987***	4.516***	-0.917***	-0.648***
	(0.004)	(0.012)	(0.013)	(0.034)	(0.017)	(0.012)	(0.020)	(0.034)
Unobhet	-1.024***	1.374***	1.015***	2.917***	0.538***	1.426***	1.024***	1.818***
	(0.013)	(0.008)	(0.023)	(0.075)	(0.028)	(0.003)	(0.009)	(0.013)

The results for both samples of large-cap and small-cap stocks are mostly consistent with the full sample of ASX Trade period and the coefficient estimates can be explained in a similar way as in *Section 5.5.4*. There are, however, a couple of differences that are worth noting when compare between the two samples of large-cap and small-cap stocks. The first distinction can be observed in the effects of initial aggressiveness. The coefficient estimates of $p^{Relative}$ for the large-cap stocks are consistent with the pooled sample and they are statistically significant for most types of order spells in both samples of buy and sell limit orders. On the other hand, the estimates of $p^{Relative}$ for the small-cap stocks are statistically less significant in both samples shown in *Table 5.11* and *Table 5.12*. In fact, they are mostly insignificant for limit order spells originating from order submission. This result implies that submitting an aggressive limit order for a smaller stock generally has a statistically less significant effect on the hazard rates of order cancellation and order revisions, including aggressive and defensive revisions, than for a larger stock in this period of ASX Trade.

Moreover, another interesting distinction is found in the sample of large-cap stocks. Unlike the sample of small-cap stocks or the pooled sample, the coefficient estimate of Δq^{Same} is positive and statistically significant for order cancellation originating from order submission of large-cap stocks in the sample of sell limit orders (as shown in *Table 5.10*). The variable Δq^{Same} measures the change in the same-side quotes and as it increases, the hazard rate of order cancellation also rises. The result reveals that when the same-side quote moves adversely away from the initial price, traders is more encouraged to cancel their limit order and submit a more aggressive one. Besides, the coefficient estimates of Δq^{Same} are also found to be significantly positive for order revision and aggressive revision which originate from order submission of large-cap stocks in the sample of sell limit orders. Therefore, in this period of ASX Trade, traders seem to revise their limit orders to sell large-cap stocks more intensively and aggressively in order to chase the market if it moves away from them. The evidence found for the sample of large-cap stocks, in deed, lends a strong support for the 'chasing hypothesis' discussed in Hasbrouck and Saar (2009).

There is no clear evidence that traders of small-cap stocks also 'chase the market' in this sample period. Nevertheless, the sample of small-cap stocks also shows a similar finding to the pooled sample and the sample of large-cap stocks in the effects of the opposite quotes. Particularly, the coefficient estimate of $\Delta q^{Opposing}$ is negative and statistically significant for order cancellation originating from limit order submission of small-cap stocks (as evident in the sample of buy limit orders in *Table 5.11*). The result signifies that when the opposite quotes become cheaper, traders of small-cap stocks have a tendency to increase the intensity of cancelling their buy limit orders to opt for market orders for executions against the more favourable quotes. The sample of buy limit orders for small-cap stocks, again, shows some evidence for the presence of the 'cost of immediacy hypothesis' in this period of ASX Trade.

Finally, the relationship between the market quality measures and the intensity of order cancellation and revision activities for both large-cap and small-cap stocks are generally consistent with the pooled sample in this period. This result is shown by the consistent signs and significance levels of the parameter estimates of *Spreads*, *Volatility*, *Market Depth* as well as *Fleeting Orders*. High-frequency traders utilise the ultra low latency in the stock market in the period of ASX Trade to form dynamic order placement strategies. Their strategies involve combinations of multiple responses to the changes in market conditions by conducting a number of limit order cancellation as well as revision activities, including aggressive and defensive revisions.

5.6. Conclusion

Dynamic limit order placement activities, their effects and determinants have been a controversial topic in market microstructure over the past decade. In the current environment, it is even more difficult to determine the effects of those activities, especially when stock exchanges around the world are racing to reduce their market latency. The Australian Stock Exchange (ASX) is a recent example where the stock market migrated its trading platform from SEATS to ITS in October 2006 and significantly reduced the exchange latency. Later in November 2010, ASX again launched the ASX Trade platform to replace ITS, which lowered the market latency even further.

Limit order revision and cancellation activities have been documented in recent studies to play an important role in forming dynamic order placement strategies. However determinants and effects of these activities have not been adequately accounted for by the existing theoretical and empirical research in the literature of market microstructure. In this chapter, dynamic order placement strategies in a low-latency environment together with limit orders' aggressiveness are examined by a new approach which utilises survival analysis with a multiple-spell duration model. The two samples undertaken in this study include the period immediately followed ASX's migration to ITS and the period subsequent to the launch of ASX Trade.

The chapter finds evidence in support for both the 'cost of immediacy hypothesis' and the 'chasing hypothesis', which is consistent with the study by Hasbrouck and Saar (2009). The results of this chapter suggest that a higher initial aggressiveness of the submitted limit order leads to a higher hazard rate of order cancellation and a lower hazard rate of order revision. Thus, when the market conditions improve (e.g. liquidity increases, spread is shortened), traders will have a tendency to cancel limit order and opt for market orders for an immediate execution. This tendency is, indeed, justified by the 'cost of immediacy hypothesis'. Moreover, the chapter also finds that when the best same-side quote moves adversely away from the initial best price, traders have a higher tendency to cancel their limit order and submit a more aggressive one; or they revise their limit order with a more aggressive price. By conducting such activities, traders in fact 'chase the market' to gain better execution opportunities. This result is consistent with the 'chasing hypothesis'.

One of the distinctions found between the samples of ITS period and ASX Trade period is the effect of changes in the opposite quotes. The sample of buy limit orders in the ASX Trade period shows significant evidence consistent with 'cost of immediacy hypothesis'. Specifically, when the opposite quotes become cheaper, traders are more motivated to cancel their existing limit orders in favour of market orders for an immediate execution. The sample of small-cap stocks also experiences some differences in the effects on the hazard rates of order cancellation and revisions, as compared to the sample of large-cap stocks. For example, submitting an aggressive limit order for a smaller stock generally has a statistically less significant effect on the hazard rates of order cancellation and order revisions, including aggressive and defensive revisions, than for a larger stock.

The results in this chapter also reconfirm the previous chapters' findings regarding the effects of market conditions on dynamic limit order placement strategies. The lower quality of the market stimulates limit order placement activities and traders respond to such market conditions by intensifying their activities of order cancellation and order revisions, including aggressive and defensive revisions. In particular, the probability of occurrence for order cancellation and revision activities is found to be higher when there is a higher level of short term volatility and a lower level of liquidity, as well as when there are more fleeting orders appear in the market.

The study of *Chapter 5* contributes to the existing literature by enhancing the current understanding of dynamic order placement strategies in a low-latency environment. The findings are not only beneficial for market participants, but they also have important policy implications which will hopefully help market regulators in their attempt to improve regulations for stock exchanges.

CHAPTER 6

CONCLUSION

6.1. Concluding Remarks

The recent studies in the market microstructure area have indicated that limit order revision and cancellation activities play an important part in forming dynamic order placement strategies. However, a number of aspects have not been adequately accounted for by the existing theoretical and empirical research in the current literature. For that reason, this thesis attempts to provide the first study that utilises survival analysis with both single-spell and multiple-spell duration models to examine dynamic limit order placement strategies. By allowing for duration dependence and addressing the unobserved heterogeneity, a multiple-spell duration analysis is probably a more appropriate tool to address the determinants and aggressiveness of dynamic of limit order placement strategies since these strategies are constructed from a series of order events rather than a single, independent order. This thesis also investigates the effects of revision and cancellation activities on the quality of the stock market, especially in a low-latency environment.

Chapter 3 employs a new approach which utilises survival analysis methodology with both single-spell and multiple-spell duration models to study dynamic limit order placement strategies and their determinants. The results are found to be consistent in suggesting that limit order placements are determined by the characteristics of the limit orders and the conditions of the stock market where the order is submitted. Specifically, limit orders with a larger size are monitored more closely, therefore they achieve a better execution rate than limit orders with a smaller size. The larger-size limit orders are, however, also revised and cancelled with a shorter duration if the market conditions are not favourable. The time-to-an-order-event tends to be shorter when there is a smaller gap between limit order price and the prevailing mid-quote. In addition, a negative and significant relationship is found between market liquidity and limit order duration, especially for limit order revision and cancellation in the early period of the ASX200. When liquidity is improved, traders tend to move quicker in an attempt to capture the newly presented opportunities in the market. Moreover, the time-to-an-order-event is seen to be shorter when the opposite-side liquidity increases and when the same-side liquidity decreases. Additional evidence is also found to show that a sell (buy) limit order has a better chance to be picked up faster if the prior transaction is a buyer (seller) initiated trade. In the sample period under study, limit order spells ending with an order cancellation have the shortest duration compared to the spells ending with an order revision or execution, for both small and large stocks, across both samples of buy and sell limit orders.

Furthermore, the empirical results suggest that a number of factors determine the hazard rates of limit order event transitions. Specifically, the probability of occurrence of limit order events is determined by factors such as limit order size, limit price, market liquidity, previous duration of the limit order spell, as well as other unobserved factors. This chapter also extends the initial study by examining dynamic limit order placement strategies in the periods that immediately followed the two major structural changes of the ASX. The study signifies that a more volatile market with a larger involvement of high-frequency trading activities may contribute to a higher hazard rate of transitions to limit order revision and cancellation.

Chapter 4 uses a simultaneous equation model to examine the effects of dynamic limit order placement strategies and their interaction with the stock market. The chapter finds that order placement activities have a direct impact on the stock market quality. Specifically, in the early period, traders increase their limit order placement activities in order to respond to a lower quality market, i.e. the market that is characterised by a lower level of liquidity and a higher level of volatility. An increase in order placement, including revision and cancellation activities, helps improve the market quality by reducing short-term volatility, narrowing the spreads and enhancing the depth of the limit order book. However, this effect is no longer observed in the periods following the structural changes of the ASX. Specifically, as the level of limit order placement activities increases, it also creates a more turbulent stock market where liquidity is reduced and volatility is heightened. This consequence can be attributed to the amount of algorithmic/high-frequency trading that is intensified when the level of trading activities increases. As a result, the net effect is a lower market quality, which is opposite to the period prior to the structural changes. Nevertheless, as market latency is lowered and technology is improved further in the later period, the adverse effects of order placement activities are reduced, as seen in the period of ASX Trade compared to the ITS period.

Most of the previous studies on order choice and placement activities mainly focus on order submission and execution but largely ignore the activities of order revision and cancellation. This chapter, however, construct measures of trading activities as full series of order submission, revision, execution and cancellation for both buy and sell limit orders. As a result, *Chapter 4* contributes to the current literature of market microstructure in two important aspects. The first major contribution is the examination of limit order revision and cancellation activities, taking into account the fact that they are a part of dynamic order placement strategies. The second major contribution of this chapter is the study of the interactions between order placement activities and stock market quality utilising a methodology which accounts for non-arbitrary linkages of limit order events.

Chapter 5 also employs the new approach of utilising survival analysis with a multiple-spell duration model to investigate dynamic order placement strategies and their aggressiveness in a low-latency market environment. A reduction in market latency has created a new trading environment where algorithmic/high-frequency trading is encouraged and they have changed the way traders manage their order placement activities. The results in this chapter suggest that a higher hazard rate of order cancellation and a lower hazard rate of order revision could be caused by a higher initial aggressiveness of the submitted limit order. When the market liquidity is improved, there is a tendency of canceling limit orders in favour of market orders in an attempt to gain an immediate execution. In addition, this chapter also finds that when the market moves away from the initial position of a limit order, the trader tends to 'chase the market' by either cancelling the submitted order and resubmitting a more aggressive one; or the trader chooses to revise the limit order with a more aggressive price. As a result, evidence is found to support for both the 'cost of immediacy hypothesis' and the 'chasing hypothesis', which are the two theories discussed in Hasbrouck and Saar (2009) to explain order placement behaviours.

Furthermore, *Chapter 5* also reconfirms the findings in the previous chapters which describe how dynamic limit order placement strategies can be affected by the conditions of the stock market. The intensity of limit order cancellation and order revisions, including aggressive and defensive revision activities, is seen to be higher when the stock market experiences a lower quality condition. A lower quality market in the sample period under study is characterised by a higher level of short term volatility and a lower level of liquidity. The market condition with a higher number of submitted fleeting orders also results in a higher probability of occurrence of order cancellation and revision activities. Moreover, this chapter also shows some distinctions in traders' behaviours when comparing the ITS period and the ASX Trade period, as well as when comparing the sample of large-cap stocks and the sample of small-cap stocks. For example, when the opposite quotes become more favourable, traders of buy limit orders in the ASX Trade period are more motivated to cancel their existing limit orders and opt for market orders with an immediate execution. The hazard rates of order cancellation and order revision, including aggressive and defensive revisions, also seem to be less affected by the initial aggressiveness of a limit order to buy or sell a small-cap stock than a large-cap stock.

The results of this thesis are indeed beneficial for stock market participants in enhancing their understanding of the effectiveness of dynamic order placement strategies. A lower latency trading environment provides means for more developments of trading algorithms. However, it also creates an arms race for high-frequency trading expansions which could eventually lead to disastrous events in the stock markets such as the market flash crash on May 6, 2010. As a result, the findings of this research also provide important policy implications which could hopefully help exchange regulators in setting appropriate regulations to ensure an efficiently functioning stock market.

6.2. Areas for Future Research

For the areas of future research, a further extension to this thesis can be conducted by employing cross sectional analysis to examine the heterogeneity of dynamic order strategies and trading speed across stocks and brokerage houses (using broker IDs). Due to different sophisticated trading algorithms employed by different investment banks and brokerage houses, variations would be expected in trading speed and order strategies across these institutions. In addition, more order revisions and better execution quality would be expected for brokerage houses that frequently trade large orders as well as institutional brokers. An event study can also be performed to examine variations of dynamic order placement strategies before and after public news releases during the trading hours. The results of these analyses can further enhance the current knowledge on the costs and benefits of fast trading strategies and their impacts on market liquidity.

REFERENCES

Ahn, H.J., Bae, K.H., and Chan, K., (2001). "Limit orders, depth and volatility: Evidence from the stock exchange of Hong Kong". *Journal of Finance*, 61, 767–788.

Angel, J., (1994). "Limit versus market orders". Working Paper, School of Business Administration, Georgetown University, Washington, D.C.

Bacidore, J., Battalio, R., and Jennings, R., (2003). "Order submission strategies, liquidity supply, and trading in pennies on the New York Stock Exchange". *Journal of Financial Markets*, 6, 337–362.

Biais, B., Foucault, T., and Moinas, S., (2011). "Equilibrium high frequency trading". Manuscript. Retrieved August, 17, 2012.

Biais, B., Hillion, P., and Spatt, C., (1995). "An empirical analysis of the limit order book and the order flow in the Paris Bourse". *Journal of Finance*, 50, 1655–1689.

Boehmer, E., Fong, K.Y.L., and Wu, J.J., (2014). "International evidence on algorithmic trading". AFA 2013 San Diego Meetings Paper.

Boizot, C., Robin, J.M., and Visser, M., (2001). "The demand for food products: An analysis of interpurchase times and purchased quantities". *The Economic Journal*, 111(470), 391-419.

Bonnal, L., Fougere, D., and Serandon, A., (1997). "Evaluating the impact of French employment policies on individual labour market histories". *Review of Economic Studies*, 64, 683-713.

Booth, A.L., Francesconi, M., and Frank, J., (2002). "Temporary jobs: Stepping stones or dead ends?". *The Economic Journal*, 112, 189– 213.

Boulatov, A. and Dierker, M., (2007). "Pricing prices". EFA 2007 Ljubljana Meetings Paper.

Brogaard, J., Hendershott, T., and Riordan, R., (2014). "High frequency trading and price discovery". *Review of Financial Studies*, 27(8), 2267-2306.

Buti, S. and Rindi, B., (2011). "Undisclosed orders and optimal submission strategies in a dynamic limit order market". IGIER Working Paper 389.

Cartea, Á. and Penalva, J., (2012). "Where is the value in high-frequency trading?" *Quarterly Journal of Finance*, 2 (3), 1-46.

Cespa, G. and Foucault, T., (2008). "Insiders-outsiders, transparency and the value of the ticker". CEPR Discussion Paper, ref. DP6794.

Chaboud, A.P., Chiquoine, B., Hjalmarsson, E., and Vega, C., (2014). "Rise of the machines: Algorithmic trading in the foreign exchange market". *The Journal of Finance*, 69(5), 2045-2084.

Chakravarty, S. and Holden, C.W., (1995). "An integrated model of market and limit orders". *Journal of Financial Intermediation*, 4, 213-241.

Cohen, K.J., Maier, S.F., Schwartz, R.A., and Whitcomb, D.K., (1981). "Transaction costs, order placement strategy, and existence of the bid-ask spread". *Journal of Political Economy*, 89, 287-305

Cohen, S.N. and Szpruch, L., (2012). "A limit order model for latency arbitrage". *Mathematics and Financial Economics*, 6, 211–227.

Coppejans, M. and Domowitz, I., (2002). "An empirical analysis of trades, orders, and cancellations in a limit order market". Working paper, Duke University.

Cox, D.R. and Oakes, D., (1984). "Analysis of survival data". Chapman and Hall, London.

Cvitanic, J. and Kirilenko, A.A., (2010). "High-frequency traders and asset prices". Working paper, California Institute of Technology and MITS loan School.

De Graaf-Zijl, M., Van den Berg, G.J., and Heyma, A., (2011). "Stepping stones for the unemployed: The effect of temporary jobs on the duration until (regular) work". *Journal of Population Economics*, 24(1), 107-139.

Devine, T.J. and Kiefer, N.M., (1991). "Empirical labor economics", OUP Catalogue, Oxford University Press, Oxford.

Diebold, F.X. and Rudebusch, G.D., (1990). "A nonparametric investigation of duration dependence in the American business cycle". *Journal of Political Economy*, 98, 596-616.

Easley, D. and Kleinberg. J., (2010). "Networks, crowds, and markets: Reasoning about a highly connected world". Cambridge University Press.

Ellul, A., Holden, C.W., Jain, P., and Jennings, R.H., (2007). "Order dynamics: Recent evidence from the NYSE". *Journal of Empirical Finance*, 14, 636-661

Engle, R. and Russell, J., (1998). "Autoregressive conditional duration: A new model for irregularly spaced transactions data". *Econometrica*, 66, 1127-1162.

Fong, K. and Liu, W.M., (2010). "Limit order revisions". *Journal of Banking and Finance*, 34, 1873-1885.

Foucault, T., (1994). "Price formation and order placement strategies in a dynamic order driven market". Department of Economics and Business, Universitat Pompeu Fabra.

Foucault, T., (1999). "Order flow composition and trading costs in a dynamic limit order market". *Journal of Financial markets*, 2(2), 99-134.

Fung, W. and Hsieh, D.A., (1997). "Empirical characteristics of dynamic trading strategies: The case of hedge funds". *Review of Financial Studies*, 10, 275-302.

Gagliarducci, S. (2005). "The dynamics of repeated temporary jobs". *Labour Economics*, 12(4), 429-448.

Gerig, A. and Michayluk, D., (2014). "Automated liquidity provision". Working paper, University of Technology, Sydney.

Glosten, L.R., (1994). "Is the electronic open limit order book inevitable?" *Journal of Finance*, 49(4), 1127-1161.

Goettler, R.L., Parlour, C.A., and Rajan, U., (2005). "Equilibrium in a dynamic limit order market". *Journal of Finance*, 60, 2149–2192.

Griffths, M., Smith, B., Turnbull, D.A., and White, R., (2000). "The costs and the determinants of order aggressiveness". *Journal of Financial Economics*, 56, 65–88.

Grossman, S.J. and Miller, M.H., (1988). "Liquidity and market structure". *Journal of Finance*, 43(3), 617-633.

Gsell, M., (2008). "Assessing the impact of algorithmic trading on markets: A simulation approach" (No. 2008/49), CFS Working Paper.

Gsell, M. and Gomber, P., (2009). “Algorithmic trading engines versus human traders: Do they behave different in securities markets”. In Proceedings of the 17th European Conference on Information Systems (ECIS), Verona, Italy.

Hall, A. and Hautsch, N., (2006). “Order aggressiveness and order book dynamics”. *Empirical Economics*, 30, 973-1005.

Ham, J.C. and Rea, S.A., (1987). “Unemployment insurance and male unemployment duration in Canada”. *Journal of Labor Economics*, 5, 325-353.

Handa, P. and Schwartz, R., (1996). “Limit order trading”. *Journal of Finance*, 51, 1835-1861.

Harris, L., (1998). “Optimal dynamic order submission strategies in some stylized trading problems”. *Financial Markets, Institutions and Instruments*, 7(2), 1-76.

Harris, L. and Hasbrouck, J., (1996). “Market vs. limit orders: The SuperDot evidence on order submission strategy”. *Journal of Financial and Quantitative Analysis*, 31, 213-231.

Hasbrouck, J. and Saar, G., (2002). “Limit orders and volatility in a hybrid market: The Island ECN”. Working paper, Department of Finance, Stern School, NYU.

Hasbrouck, J. and Saar, G., (2009). “Technology and liquidity provision: The blurring of traditional definitions”. *Journal of Financial Markets*, 12, 143-172.

Hasbrouck, J. and Saar, G., (2013). “Low-Latency Trading”. *Journal of Financial Markets*, 16, 646-679

Heckman, J.J. and Walker, J.R., (1990), “The relationship between wages and income and the timing and spacing of births”. *Econometrica*, 58, 1411-1441.

Hendershott, T.J., Jones, C.M., and Menkveld, A.J., (2011). "Does algorithmic trading improve liquidity?" *Journal of Finance*, 66, 1–33.

Hendershott, T.J. and Moulton, P.C., (2011). "Automation, speed and market quality". *Journal of Financial Markets*, 14, 568–604.

Hendershott, T.J. and Riordan, R., (2013). "Algorithmic trading and the market for liquidity". *Journal of Financial and Quantitative Analysis*, 48 (04), 1001-1024.

Hoffmann, P., (2010). "Algorithmic trading in a dynamic limit order market". Working paper, Universitat Pompeu Fabra.

Hollifield, B., Miller, R.A., and Sandas, P., (2004). "Empirical analysis of limit order markets". *Review of Economic Studies*, 71, 1027-1063

Honoré, B.E., (1993). "Identification results for duration models with multiple spells". *The Review of Economic Studies*, 60(1), 241-246.

Horvath, W.J., (1968), "A statistical model for the duration of wars and strikes". *Behavioral Science*, 13, 24.

Jarrow, R., Kchia, Y., and Protter, P., (2011). "How to detect an asset bubble". *SIAM Journal on Financial Mathematics*, 2(1), 839-865.

Jovanovic, B. and Menkveld, A.J., (2011). "Middlemen in limit-order markets". Western Finance Association (WFA).

Kalbfleisch, J.D. and Prentice, R.L., (2011). "The statistical analysis of failure time data". (Vol. 360), John Wiley & Sons.

Kennan, J.F., (1985). "The duration of contract strikes in U.S. manufacturing". *Journal of Econometrics*, 28, 5-28.

Kirilenko, A.A., Kyle, A.S., Samadi, M., and Tuzun, T., (2014). "The flash crash: The impact of high frequency trading on an electronic market". Working paper, CFTC and University of Maryland.

Lancaster, T., (1992). "The econometric analysis of transition data". Cambridge University Press, Cambridge.

Lauricella, T. and McKay, P., (2010). "Dow takes a harrowing 1,010.14-point trip". Wall Street Journal (May 7, 2010).

Lillard, L.A., (1993). "Simultaneous equations for hazards: Marriage duration and fertility timing". *Journal of Econometrics*, 56, 189-217.

Lillard, L.A. and Panis, C.W.A., (1996). "Marital status and mortality: The role of health". *Demography*, 33, 313-327.

Lindstrom, D.P., (1996), "Economic opportunity in Mexico and return migration from the United States". *Demography*, 33, 357-374.

Liu, W.-M, (2009). "Monitoring and limit order submission risks". *Journal of Financial Markets*, 12, 107-141.

Lo, A.W. and Farmer, J.D., (1999). "Frontiers of finance: Evolution and efficient markets". *Proceedings of the National Academy of Sciences*, 96(18), 9991-9992.

Lo, A.W., MacKinlay, A.C., and Zhang, J., (2002). "Econometric models of limit order executions". *Journal of Financial Economics*, 65, 31-71.

Martinez, V.H. and Rosu, I., (2013). "High frequency traders, news and volatility". AFA 2013 San Diego Meetings Paper.

Menkhoff, L. and Schmeling, M., (2010). "Whose trades convey information? Evidence from a cross-section of traders". *Journal of Financial Markets*, 13, 101-128.

Moallemi, C.C. and Saglam, M., (2010). "The cost of latency". SSRN eLibrary.

Newman, J.L. and McCulloch, C.E., (1984). "A hazard rate approach to the timing of births". *Econometrica*, 52, 939-961.

Nilsen, Ø.A. and Schiantarelli, F., (2003). "Zeros and lumps in investment: Empirical evidence on irreversibilities and nonconvexities". *Review of Economics and Statistics*, 85(4), 1021-1037.

Pagnotta, E.S. and Philippon, T., (2013). "Competing on speed". Working paper, New York University.

Pakes, A. and Schankerman, M., (1984). "The rate of obsolescence of patents, research gestation lags, and the private rate of return to research resources". In *R&D, patents, and productivity* (pp. 73-88), University of Chicago Press.

Parlour, C., (1998). "Price dynamics in limit order markets". *Review of Financial Studies*, 11, 789–816

Prix, J., Loistl, O., and Huetl, M., (2007). "Algorithmic trading patterns in Xetra orders". *European Journal of Finance,* 13, 717–739.

Ranaldo, A., (2004). "Order aggressiveness in limit order markets". *Journal of Financial Markets*, 7, 53-74.

Riordan, R. and Storkenmaier, A., (2012). "Latency, liquidity and price discovery". *Journal of Financial Markets*, 15, 416–437.

Sandas, P., (2001). “Adverse selection and competitive market making: Empirical evidence from a limit order market”. *Review of Financial Studies*, 14(3), 705–734.

Van den Berg, G.J., (2001). “Duration models: Specification, identification and multiple durations”. *Handbook of Econometrics*, 5, 3381-3460.

Van den Berg, G.J. and Lindeboom, M., (1998). “Attrition in panel survey data and the estimation of multi-state labor market models”. *Journal of Human Resources*, 33, 458-478.

Van Ours, J.C., (2004). “The locking-in effect of subsidized jobs”. *Journal of Comparative Economics*, 32, 37-55.

Vilcassim, N.J. and Jain, D.C., (1991). “Modeling purchase-timing and brandswitching behavior incorporating explanatory variables and unobserved heterogeneity”. *Journal of Marketing Research*, 28, 29-41.

Xu, Y., (2009). “Order aggressiveness on the ASX market”. *International Journal of Economics and Finance*, 1, 51-75.

Yeo, W., (2006). “Understanding cancellation and resubmission of limit orders”. 19th Australasian Finance and Banking Conference, Sydney, Australia.

APPENDICES

Table A.1: Multiple-Spell Duration Analysis of Buy Limit Orders of Large-Cap Stocks in the ITS Period (August 2007 Sample)

This table presents the results for the multiple-spell duration survival analysis of buy limit orders of large-cap stocks in the period that the ASX operated the Integrated Trading System (August 2007 sample). The table describes the study of limit order dynamics as a sequence of multiple limit order events. The estimation model used in this survival analysis is the Proportional Hazard model under the exponential distribution for limit order times. Definitions of the explanatory variables are given in the text. Panel A reports the results for limit order executions (including full and partial), limit order revisions and limit order cancellations that followed a limit order submission. Panel B reports the results for the limit order events that followed a limit order revision and Panel C reports the results for the limit order events that followed a limit order partial execution. The coefficient estimates are presented for each of the variable and the standard errors are reported in the parentheses. ***, **, * denote statistical significance at the 1, 5 and 10 percent level respectively.

Panel A

ORIGIN	**Submission**			
DESTINATION	***Full Execution***	***Partial Execution***	***Revision***	***Cancellation***
PRICEGAP	0.226***	0.197***	0.067***	0.135***
	(0.004)	(0.009)	(0.005)	(0.006)
INITRADE	-0.150***	-0.102***	-0.032***	-0.090***
	(0.004)	(0.008)	(0.004)	(0.005)
SSLIQUIDITY	-0.654***	-0.435***	-0.557***	-1.456***
	(0.005)	(0.012)	(0.013)	(0.016)
MKDPR	-0.696***	-0.972***	1.069***	1.126***
	(0.010)	(0.021)	(0.020)	(0.026)
OSLIQUIDITY	0.160***	0.035***	0.054***	-0.058***
	(0.004)	(0.009)	(0.004)	(0.005)
ORDSIZE	0.026***	-0.018*	-0.613***	0.480***
	(0.004)	(0.011)	(0.013)	(0.015)
CONST	0.775***	1.190***	0.334***	1.415***
	(0.005)	(0.009)	(0.005)	(0.006)
UNOBHET	0.236***	0.373***	0.021***	0.534***
	(0.004)	(0.007)	(0.005)	(0.004)

Panel B

ORIGIN	**Revision**				**Partial Execution**			
DESTINATION	***Full Execution***	***Partial Execution***	***Revision***	***Cancellation***	***Full Execution***	***Partial Execution***	***Revision***	***Cancellation***
PRICEGAP	0.136***	0.200***	0.029***	0.013	0.026***	0.082***	0.072***	0.130***
	(0.007)	(0.023)	(0.003)	(0.013)	(0.007)	(0.009)	(0.015)	(0.028)
INITRADE	-0.043***	-0.050***	-0.008***	-0.012	-0.063***	-0.135***	-0.108***	-0.416***
	(0.005)	(0.012)	(0.003)	(0.012)	(0.009)	(0.011)	(0.014)	(0.023)
SSLIQUIDITY	-0.505***	-0.458***	-0.169***	-0.063**	-0.279***	-0.495***	-0.130***	-0.734***
	(0.010)	(0.028)	(0.005)	(0.030)	(0.010)	(0.016)	(0.015)	(0.024)
MKDPR	-0.749***	-0.598***	0.066***	1.039***	-0.078***	-0.049***	-0.021	0.019
	(0.014)	(0.021)	(0.005)	(0.033)	(0.008)	(0.010)	(0.013)	(0.021)
OSLIQUIDITY	-0.012**	-0.049***	-0.030***	0.237***	0.125***	0.052***	0.065***	0.199***
	(0.005)	(0.013)	(0.003)	(0.014)	(0.007)	(0.011)	(0.014)	(0.022)
ORDSIZE	0.144***	-0.069***	0.082***	-1.071***	0.163***	-0.029***	0.017	0.084***
	(0.007)	(0.023)	(0.005)	(0.032)	(0.009)	(0.011)	(0.014)	(0.022)
PREVDUR	-0.018***	-0.014***	-0.003***	-0.015***	-0.002***	-0.001***	-0.008***	-0.008***
	(<.001)	(0.001)	(<.001)	(<.001)	(<.001)	(<.001)	(0.001)	(0.002)
CONST	1.162***	1.529***	0.848***	1.254***	2.359***	2.739***	0.620***	2.029***
	(0.007)	(0.018)	(0.003)	(0.016)	(0.009)	(0.011)	(0.016)	(0.025)
UNOBHET	-0.301***	-0.028*	-0.255***	0.421***	0.141***	0.317***	-0.265***	0.551***
	(0.008)	(0.015)	(0.004)	(0.011)	(0.007)	(0.008)	(0.019)	(0.016)

Table A.2: Multiple-Spell Duration Analysis of Sell Limit Orders of Large-Cap Stocks in the ITS Period (August 2007 Sample)

This table presents the results for the multiple-spell duration survival analysis of sell limit orders of large-cap stocks in the period that the ASX operated the Integrated Trading System (August 2007 sample). The table describes the study of limit order dynamics as a sequence of multiple limit order events. The estimation model used in this survival analysis is the Proportional Hazard model under the exponential distribution for limit order times. Definitions of the explanatory variables are given in the text. Panel A reports the results for limit order executions (including full and partial), limit order revisions and limit order cancellations that followed a limit order submission. Panel B reports the results for the limit order events that followed a limit order revision and Panel C reports the results for the limit order events that followed a limit order partial execution. The coefficient estimates are presented for each of the variable and the standard errors are reported in the parentheses. ***, **, * denote statistical significance at the 1, 5 and 10 percent level respectively.

Panel A

ORIGIN	**Submission**			
DESTINATION	***Full Execution***	***Partial Execution***	***Revision***	***Cancellation***
PRICEGAP	-0.110***	-0.182***	0.023	0.151***
	(0.012)	(0.033)	(0.018)	(0.006)
INITRADE	0.067***	0.016**	0.007	-0.055***
	(0.004)	(0.007)	(0.004)	(0.005)
SSLIQUIDITY	-0.681***	-0.621***	-0.934***	-0.017***
	(0.005)	(0.011)	(0.044)	(0.001)
MKDPR	0.200***	0.875***	-0.860***	-0.381***
	(0.015)	(0.015)	(0.044)	(0.042)
OSLIQUIDITY	0.101***	0.003	-0.041***	-0.123***
	(0.005)	(0.008)	(0.005)	(0.002)
ORDSIZE	0.149***	0.216***	-0.052***	-0.013***
	(0.012)	(0.033)	(0.016)	(0.001)
CONST	0.826***	1.193***	0.597***	2.601***
	(0.005)	(0.008)	(0.005)	(0.018)
UNOBHET	-0.008*	0.255***	0.129***	0.539***
	(0.005)	(0.007)	(0.005)	(0.004)

Panel B

ORIGIN	**Revision**				**Partial Execution**			
DESTINATION	***Full Execution***	***Partial Execution***	***Revision***	***Cancellation***	***Full Execution***	***Partial Execution***	***Revision***	***Cancellation***
PRICEGAP	-0.135***	-0.163***	-0.029*	0.064***	-0.073***	0.004	-0.035	-0.144***
	(0.013)	(0.048)	(0.018)	(0.010)	(0.020)	(0.023)	(0.039)	(0.054)
INITRADE	-0.051***	-0.028***	-0.034***	-0.039***	0.065***	0.144***	0.137***	0.258***
	(0.005)	(0.011)	(0.003)	(0.012)	(0.007)	(0.006)	(0.014)	(0.022)
SSLIQUIDITY	-0.477***	-0.505***	0.020*	-0.006***	-0.146***	-0.279***	-0.202***	-0.665***
	(0.009)	(0.020)	(0.011)	(0.001)	(0.008)	(0.010)	(0.013)	(0.019)
MKDPR	0.639***	0.588***	-0.027***	-0.001***	0.079***	0.001	0.004	0.040
	(0.008)	(0.017)	(0.008)	(<.001)	(0.009)	(0.004)	(0.015)	(0.025)
OSLIQUIDITY	-0.004	-0.056***	-0.070***	0.019***	0.123***	0.121***	0.093***	0.245***
	(0.006)	(0.011)	(0.003)	(0.005)	(0.007)	(0.007)	(0.014)	(0.020)
ORDSIZE	0.176***	0.170***	-0.021	-0.004***	0.117***	0.012	0.057	0.237***
	(0.014)	(0.051)	(0.016)	(0.001)	(0.020)	(0.022)	(0.040)	(0.056)
PREVDUR	-0.013***	-0.012***	-0.004***	-0.018***	-0.002***	-0.003***	-0.009***	-0.014***
	(<.001)	(<.001)	(<.001)	(<.001)	(<.001)	(<.001)	(0.001)	(0.002)
CONST	1.077***	1.482***	0.934***	1.438***	2.397***	2.570***	0.896***	2.214***
	(0.007)	(0.014)	(0.003)	(0.036)	(0.007)	(0.007)	(0.015)	(0.021)
UNOBHET	-0.428***	-0.136***	-0.198***	0.393***	0.033***	0.133***	-0.119***	0.539***
	(0.009)	(0.013)	(0.004)	(0.010)	(0.007)	(0.006)	(0.016)	(0.014)

Table A.3: Multiple-Spell Duration Analysis of Buy Limit Orders of Small-Cap Stocks in the ITS Period (August 2007 Sample)

This table presents the results for the multiple-spell duration survival analysis of buy limit orders of small-cap stocks in the period that the ASX operated the Integrated Trading System (August 2007 sample). The table describes the study of limit order dynamics as a sequence of multiple limit order events. The estimation model used in this survival analysis is the Proportional Hazard model under the exponential distribution for limit order times. Definitions of the explanatory variables are given in the text. Panel A reports the results for limit order executions (including full and partial), limit order revisions and limit order cancellations that followed a limit order submission. Panel B reports the results for the limit order events that followed a limit order revision and Panel C reports the results for the limit order events that followed a limit order partial execution. The coefficient estimates are presented for each of the variable and the standard errors are reported in the parentheses. ***, **, * denote statistical significance at the 1, 5 and 10 percent level respectively.

Panel A

ORIGIN	**Submission**			
DESTINATION	***Full Execution***	***Partial Execution***	***Revision***	***Cancellation***
PRICEGAP	0.155***	0.240***	0.073***	0.125***
	(0.009)	(0.017)	(0.010)	(0.007)
INITRADE	-0.011	-0.038**	0.029***	-0.018***
	(0.009)	(0.017)	(0.009)	(0.007)
SSLIQUIDITY	-0.829***	-0.916***	-0.300***	-0.578***
	(0.011)	(0.028)	(0.012)	(0.009)
MKDPR	-0.544***	-0.640***	0.081***	0.076***
	(0.013)	(0.023)	(0.009)	(0.016)
OSLIQUIDITY	-0.067***	-0.025	-0.237***	-0.350***
	(0.010)	(0.021)	(0.011)	(0.009)
ORDSIZE	0.205***	0.091***	-0.106***	0.097***
	(0.010)	(0.023)	(0.010)	(0.009)
CONST	-0.427***	-0.185***	-0.541***	0.394***
	(0.010)	(0.021)	(0.011)	(0.008)
UNOBHET	-0.043***	0.308***	-0.031***	0.263***
	(0.010)	(0.016)	(0.012)	(0.007)

Panel B

ORIGIN	**Revision**				**Partial Execution**			
DESTINATION	***Full Execution***	***Partial Execution***	***Revision***	***Cancellation***	***Full Execution***	***Partial Execution***	***Revision***	***Cancellation***
PRICEGAP	0.111***	0.124***	0.081***	0.039*	0.049***	0.192***	0.108***	0.026
	(0.013)	(0.029)	(0.007)	(0.022)	(0.018)	(0.020)	(0.041)	(0.039)
INITRADE	0.002	0.059*	-0.024***	0.046*	-0.192***	-0.322***	-0.139***	-0.447***
	(0.014)	(0.032)	(0.007)	(0.024)	(0.025)	(0.027)	(0.043)	(0.052)
SSLIQUIDITY	-0.977***	-1.022***	-0.297***	-0.020	-0.655***	-0.995***	-0.756***	-0.712***
	(0.033)	(0.095)	(0.008)	(0.030)	(0.027)	(0.032)	(0.049)	(0.054)
MKDPR	-0.368***	-0.489***	0.014**	0.102**	-0.058**	-0.012	0.013	0.026
	(0.014)	(0.028)	(0.007)	(0.043)	(0.024)	(0.024)	(0.040)	(0.049)
OSLIQUIDITY	-0.092***	-0.165***	-0.446***	-0.028	0.091***	0.233***	0.305***	0.148***
	(0.015)	(0.037)	(0.008)	(0.028)	(0.021)	(0.021)	(0.047)	(0.050)
ORDSIZE	0.260***	0.135*	0.218***	-0.823***	0.116***	-0.351***	0.083*	0.497***
	(0.022)	(0.078)	(0.008)	(0.029)	(0.024)	(0.023)	(0.044)	(0.048)
PREVDUR	-0.013***	-0.007***	-0.001***	-0.007***	-0.003***	-0.003***	-0.002*	-0.016***
	(0.001)	(0.001)	(<.001)	(0.001)	(<.001)	(<.001)	(0.001)	(0.002)
CONST	0.419***	0.650***	0.502***	0.316***	1.643***	2.328***	0.183***	2.293***
	(0.024)	(0.058)	(0.009)	(0.033)	(0.024)	(0.024)	(0.053)	(0.052)
UNOBHET	-0.140***	0.136***	0.069***	0.297***	0.447***	0.601***	0.217***	0.853***
	(0.018)	(0.034)	(0.008)	(0.024)	(0.016)	(0.014)	(0.043)	(0.027)

Table A.4: Multiple-Spell Duration Analysis of Sell Limit Orders of Small-Cap Stocks in the ITS Period (August 2007 Sample)

This table presents the results for the multiple-spell duration survival analysis of sell limit orders of small-cap stocks in the period that the ASX operated the Integrated Trading System (August 2007 sample). The table describes the study of limit order dynamics as a sequence of multiple limit order events. The estimation model used in this survival analysis is the Proportional Hazard model under the exponential distribution for limit order times. Definitions of the explanatory variables are given in the text. Panel A reports the results for limit order executions (including full and partial), limit order revisions and limit order cancellations that followed a limit order submission. Panel B reports the results for the limit order events that followed a limit order revision and Panel C reports the results for the limit order events that followed a limit order partial execution. The coefficient estimates are presented for each of the variable and the standard errors are reported in the parentheses. ***, **, * denote statistical significance at the 1, 5 and 10 percent level respectively.

Panel A

ORIGIN	**Submission**			
DESTINATION	***Full Execution***	***Partial Execution***	***Revision***	***Cancellation***
PRICEGAP	-0.510***	-0.757***	-0.089***	-0.575***
	(0.025)	(0.065)	(0.034)	(0.045)
INITRADE	-0.037***	-0.096***	-0.079***	-0.062***
	(0.009)	(0.015)	(0.010)	(0.007)
SSLIQUIDITY	-0.936***	-1.169***	-0.836***	-0.249***
	(0.011)	(0.023)	(0.023)	(0.004)
MKDPR	0.425***	0.578***	-0.699***	-0.357***
	(0.015)	(0.019)	(0.024)	(0.176)
OSLIQUIDITY	0.035***	0.028	-0.299***	-0.149***
	(0.010)	(0.019)	(0.012)	(0.004)
ORDSIZE	0.592***	0.841***	-0.027	0.038***
	(0.024)	(0.068)	(0.027)	(0.004)
CONST	-0.386***	-0.312***	-0.278***	3.425***
	(0.010)	(0.018)	(0.012)	(0.031)
UNOBHET	-0.189***	0.158***	0.081***	0.187***
	(0.012)	(0.016)	(0.011)	(0.007)

Panel B

ORIGIN / DESTINATION	Revision				Partial Execution			
	Full Execution	Partial Execution	Revision	Cancellation	Full Execution	Partial Execution	Revision	Cancellation
PRICEGAP	-0.329***	-0.956***	-0.309***	2.483***	-0.071**	0.380***	0.002	-0.515***
	(0.032)	(0.112)	(0.019)	(0.163)	(0.030)	(0.030)	(0.057)	(0.113)
INITRADE	0.011	-0.030	-0.038***	-0.089***	0.125***	0.164***	0.102**	0.387***
	(0.015)	(0.029)	(0.007)	(0.024)	(0.020)	(0.016)	(0.042)	(0.041)
SSLIQUIDITY	-1.248***	-1.686***	-0.360***	-0.086***	-0.531***	-0.648***	-0.662***	-0.665***
	(0.032)	(0.081)	(0.009)	(0.014)	(0.025)	(0.022)	(0.045)	(0.046)
MKDPR	0.307***	0.347***	-0.258***	0.239*	0.039**	-0.024*	-0.039	0.016
	(0.016)	(0.025)	(0.010)	(0.138)	(0.017)	(0.014)	(0.040)	(0.032)
OSLIQUIDITY	0.047***	-0.065**	-0.282***	-0.087***	0.092***	0.095***	0.236***	0.249***
	(0.016)	(0.032)	(0.009)	(0.013)	(0.019)	(0.015)	(0.044)	(0.044)
ORDSIZE	0.475***	1.124***	0.297***	-0.201***	0.141***	-0.414***	0.131**	0.590***
	(0.033)	(0.121)	(0.018)	(0.011)	(0.032)	(0.028)	(0.057)	(0.113)
PREVDUR	-0.012***	-0.006***	-0.002***	-0.012***	-0.002***	-0.001***	-0.001	-0.016***
	(0.001)	(0.001)	(<.001)	(0.001)	(<.001)	(<.001)	(0.001)	(0.003)
CONST	0.498***	0.717***	0.541***	3.691***	1.623***	1.866***	0.442***	2.306***
	(0.023)	(0.047)	(0.010)	(0.114)	(0.022)	(0.017)	(0.050)	(0.046)
UNOBHET	-0.230***	0.038	0.081***	0.486***	0.305***	0.423***	0.367***	0.792***
	(0.020)	(0.032)	(0.008)	(0.020)	(0.016)	(0.011)	(0.035)	(0.024)

Table A.5: Multiple-Spell Duration Analysis of Buy Limit Orders of Large-Cap Stocks in the ASX Trade Period (August 2011 Sample)

This table presents the results for the multiple-spell duration survival analysis of buy limit orders of large-cap stocks in the period that the ASX Trade was in operation (August 2011 sample). The table describes the study of limit order dynamics as a sequence of multiple limit order events. The estimation model used in this survival analysis is the Proportional Hazard model under the exponential distribution for limit order times. Definitions of the explanatory variables are given in the text. Panel A reports the results for limit order executions (including full and partial), limit order revisions and limit order cancellations that followed a limit order submission. Panel B reports the results for the limit order events that followed a limit order revision and Panel C reports the results for the limit order events that followed a limit order partial execution. The coefficient estimates are presented for each of the variable and the standard errors are reported in the parentheses. ***, **, * denote statistical significance at the 1, 5 and 10 percent level respectively.

Panel A

ORIGIN	**Submission**			
DESTINATION	***Full Execution***	***Partial Execution***	***Revision***	***Cancellation***
PRICEGAP	-0.038***	0.220***	0.098***	0.025***
	(0.012)	(0.008)	(0.003)	(0.002)
INITRADE	0.178***	0.022***	-0.071***	-0.049***
	(0.012)	(0.008)	(0.003)	(0.002)
SSLIQUIDITY	0.403***	-1.239***	-0.462***	-0.147***
	(0.016)	(0.009)	(0.005)	(0.003)
MKDPR	-0.705***	-0.903***	-0.036***	0.254***
	(0.021)	(0.014)	(0.004)	(0.005)
OSLIQUIDITY	-0.080***	0.062***	-0.268***	-0.195***
	(0.012)	(0.008)	(0.004)	(0.002)
ORDSIZE	0.377***	0.663***	0.498***	-0.327***
	(0.015)	(0.008)	(0.004)	(0.003)
CONST	8.038***	3.321***	2.584***	2.164***
	(0.013)	(0.009)	(0.004)	(0.003)
UNOBHET	0.200***	0.405***	0.413***	0.362***
	(0.011)	(0.007)	(0.003)	(0.002)

Panel B

ORIGIN	**Revision**				**Partial Execution**			
DESTINATION	*Full Execution*	*Partial Execution*	*Revision*	*Cancellation*	*Full Execution*	*Partial Execution*	*Revision*	*Cancellation*
PRICEGAP	0.281***	0.226***	0.090***	0.009*	-0.007	0.138***	0.095***	0.100***
	(0.018)	(0.014)	(0.003)	(0.005)	(0.026)	(0.017)	(0.033)	(0.024)
INITRADE	-0.001	0.070***	-0.020***	-0.133***	0.079**	-0.068***	-0.346***	-0.214***
	(0.013)	(0.012)	(0.003)	(0.005)	(0.032)	(0.023)	(0.026)	(0.028)
SSLIQUIDITY	-2.618***	-1.238***	-0.530***	-0.109***	-0.125**	-0.748***	-0.965***	-0.841***
	(0.025)	(0.020)	(0.003)	(0.007)	(0.050)	(0.028)	(0.052)	(0.035)
MKDPR	-0.718***	-0.794***	-0.156***	-0.208***	-0.572***	-0.500***	-0.114**	-0.150***
	(0.018)	(0.017)	(0.005)	(0.006)	(0.029)	(0.035)	(0.046)	(0.024)
OSLIQUIDITY	0.369***	-0.061***	-0.403***	-0.220***	0.029	0.071***	-0.161***	-0.295***
	(0.015)	(0.012)	(0.003)	(0.006)	(0.029)	(0.018)	(0.024)	(0.026)
ORDSIZE	0.749***	0.869***	0.707***	0.487***	0.052	-0.089***	1.314***	1.253***
	(0.018)	(0.013)	(0.003)	(0.007)	(0.039)	(0.020)	(0.076)	(0.041)
PREVDUR	-0.024***	-0.020***	-0.017***	-0.035***	-0.013***	-0.002***	0.011***	-0.036***
	(0.001)	(0.001)	(<.001)	(0.001)	(0.001)	(0.001)	(0.003)	(0.004)
CONST	5.671***	3.399***	5.195***	3.670***	9.185***	6.928***	6.636***	6.997***
	(0.023)	(0.017)	(0.004)	(0.007)	(0.032)	(0.022)	(0.029)	(0.027)
UNOBHET	0.653***	0.283***	0.983***	0.648***	1.175***	1.180***	1.353***	1.459***
	(0.010)	(0.012)	(0.002)	(0.004)	(0.012)	(0.008)	(0.010)	(0.009)

Table A.6: Multiple-Spell Duration Analysis of Sell Limit Orders of Large-Cap Stocks in the ASX Trade Period (August 2011 Sample)

This table presents the results for the multiple-spell duration survival analysis of sell limit orders of large-cap stocks in the period that the ASX Trade was in operation (August 2011 sample). The table describes the study of limit order dynamics as a sequence of multiple limit order events. The estimation model used in this survival analysis is the Proportional Hazard model under the exponential distribution for limit order times. Definitions of the explanatory variables are given in the text. Panel A reports the results for limit order executions (including full and partial), limit order revisions and limit order cancellations that followed a limit order submission. Panel B reports the results for the limit order events that followed a limit order revision and Panel C reports the results for the limit order events that followed a limit order partial execution. The coefficient estimates are presented for each of the variable and the standard errors are reported in the parentheses. ***, **, * denote statistical significance at the 1, 5 and 10 percent level respectively.

Panel A

ORIGIN	**Submission**			
DESTINATION	***Full Execution***	***Partial Execution***	***Revision***	***Cancellation***
PRICEGAP	0.155***	-0.018**	-0.613***	0.598***
	(0.020)	(0.008)	(0.015)	(0.012)
INITRADE	0.065***	0.022***	0.003	0.012***
	(0.007)	(0.004)	(0.003)	(0.002)
SSLIQUIDITY	-1.761***	-1.122***	-2.160***	-0.585***
	(0.007)	(0.005)	(0.025)	(0.007)
MKDPR	2.227***	1.681***	-2.323***	-0.311***
	(0.064)	(0.026)	(0.025)	(0.007)
OSLIQUIDITY	0.102***	0.053***	-0.294***	-0.215***
	(0.007)	(0.004)	(0.003)	(0.003)
ORDSIZE	-0.114***	0.041***	0.441***	-0.589***
	(0.020)	(0.008)	(0.011)	(0.010)
CONST	3.946***	1.777***	2.485***	2.264***
	(0.009)	(0.005)	(0.004)	(0.003)
UNOBHET	0.701***	0.054***	0.318***	0.431***
	(0.005)	(0.004)	(0.003)	(0.002)

Panel B

ORIGIN	**Revision**				**Partial Execution**			
DESTINATION	*Full Execution*	*Partial Execution*	*Revision*	*Cancellation*	*Full Execution*	*Partial Execution*	*Revision*	*Cancellation*
PRICEGAP	-0.159***	-0.089***	-0.912***	-0.255***	0.054**	-0.650***	-0.527***	-0.702***
	(0.033)	(0.010)	(0.011)	(0.010)	(0.024)	(0.033)	(0.053)	(0.062)
INITRADE	-0.027**	-0.011**	-0.058***	0.013***	0.321***	0.657***	0.399***	0.206***
	(0.011)	(0.005)	(0.003)	(0.005)	(0.009)	(0.013)	(0.024)	(0.025)
SSLIQUIDITY	-1.405***	-0.813***	-0.560***	-0.031***	-1.187***	-1.002***	-0.467***	-0.563***
	(0.014)	(0.007)	(0.005)	(0.006)	(0.013)	(0.017)	(0.026)	(0.031)
MKDPR	3.078***	2.739***	-0.985***	-0.119***	0.005	0.003	0.027*	0.100***
	(0.119)	(0.063)	(0.011)	(0.020)	(0.017)	(0.006)	(0.014)	(0.018)
OSLIQUIDITY	0.330***	-0.022***	-0.340***	-0.217***	0.033***	0.398***	-0.260***	-0.115***
	(0.012)	(0.006)	(0.003)	(0.006)	(0.012)	(0.014)	(0.023)	(0.025)
ORDSIZE	0.291***	0.100***	0.962***	0.265***	-0.069***	0.885***	0.539***	0.814***
	(0.035)	(0.010)	(0.012)	(0.011)	(0.023)	(0.038)	(0.057)	(0.077)
PREVDUR	-0.014***	-0.022***	-0.016***	-0.034***	0.001	-0.005***	0.008***	-0.026***
	(0.001)	(0.001)	(<.001)	(0.001)	(<.001)	(0.001)	(0.002)	(0.003)
CONST	3.890***	1.986***	5.164***	3.524***	5.845***	6.544***	6.571***	7.210***
	(0.015)	(0.006)	(0.004)	(0.007)	(0.012)	(0.015)	(0.028)	(0.026)
UNOBHET	0.619***	-0.274***	0.986***	0.592***	1.104***	1.256***	1.349***	1.466***
	(0.009)	(0.008)	(0.002)	(0.004)	(0.005)	(0.006)	(0.009)	(0.009)

Table A.7: Multiple-Spell Duration Analysis of Buy Limit Orders of Small-Cap Stocks in the ASX Trade Period (August 2011 Sample)

This table presents the results for the multiple-spell duration survival analysis of buy limit orders of small-cap stocks in the period that the ASX Trade was in operation (August 2011 sample). The table describes the study of limit order dynamics as a sequence of multiple limit order events. The estimation model used in this survival analysis is the Proportional Hazard model under the exponential distribution for limit order times. Definitions of the explanatory variables are given in the text. Panel A reports the results for limit order executions (including full and partial), limit order revisions and limit order cancellations that followed a limit order submission. Panel B reports the results for the limit order events that followed a limit order revision and Panel C reports the results for the limit order events that followed a limit order partial execution. The coefficient estimates are presented for each of the variable and the standard errors are reported in the parentheses. ***, **, * denote statistical significance at the 1, 5 and 10 percent level respectively.

Panel A

ORIGIN	**Submission**			
DESTINATION	***Full Execution***	***Partial Execution***	***Revision***	***Cancellation***
PRICEGAP	0.056**	0.307***	0.088***	0.064***
	(0.022)	(0.024)	(0.007)	(0.003)
INITRADE	0.030	0.060***	0.007	-0.054***
	(0.020)	(0.022)	(0.006)	(0.003)
SSLIQUIDITY	-0.208***	-1.992***	-0.282***	-0.237***
	(0.026)	(0.024)	(0.009)	(0.004)
MKDPR	-0.252***	-0.602***	0.078***	0.379***
	(0.037)	(0.025)	(0.006)	(0.015)
OSLIQUIDITY	0.192***	0.095***	-0.251***	-0.016***
	(0.021)	(0.021)	(0.008)	(0.004)
ORDSIZE	0.416***	1.015***	-0.147***	-0.025***
	(0.020)	(0.022)	(0.007)	(0.003)
CONST	8.005***	2.836***	0.377***	0.630***
	(0.023)	(0.025)	(0.008)	(0.004)
UNOBHET	-0.195***	0.757***	0.019**	0.092***
	(0.026)	(0.014)	(0.008)	(0.003)

Panel B

ORIGIN	**Revision**				**Partial Execution**			
DESTINATION	***Full Execution***	***Partial Execution***	***Revision***	***Cancellation***	***Full Execution***	***Partial Execution***	***Revision***	***Cancellation***
PRICEGAP	0.198***	0.241***	-0.007	0.004	0.079*	0.215***	0.420***	0.146***
	(0.033)	(0.030)	(0.006)	(0.013)	(0.047)	(0.030)	(0.059)	(0.054)
INITRADE	0.023	0.121***	-0.405***	-0.140***	0.095	-0.458***	-0.392***	-0.234***
	(0.031)	(0.037)	(0.007)	(0.013)	(0.075)	(0.045)	(0.067)	(0.066)
SSLIQUIDITY	-3.482***	-2.819***	-0.071***	-0.264***	-1.079***	-1.240***	-1.670***	-0.956***
	(0.060)	(0.067)	(0.009)	(0.018)	(0.112)	(0.062)	(0.082)	(0.079)
MKDPR	-0.449***	-0.560***	0.436***	1.640***	-0.575***	-0.024	-0.198***	-0.130***
	(0.022)	(0.034)	(0.009)	(0.020)	(0.053)	(0.026)	(0.052)	(0.050)
OSLIQUIDITY	0.447***	0.276***	0.067***	-0.015	0.023	-0.091**	0.718***	0.159**
	(0.035)	(0.040)	(0.009)	(0.017)	(0.081)	(0.040)	(0.064)	(0.063)
ORDSIZE	0.828***	1.724***	0.477***	-0.306***	0.510***	0.144***	1.021***	1.323***
	(0.041)	(0.046)	(0.008)	(0.015)	(0.077)	(0.043)	(0.067)	(0.061)
PREVDUR	-0.023***	-0.016***	-0.007***	-0.024***	-0.018***	-0.003***	0.004	-0.014***
	(0.001)	(0.001)	(<.001)	(0.001)	(0.002)	(0.001)	(0.002)	(0.003)
CONST	6.174***	3.846***	2.828***	1.857***	9.310***	6.728***	5.994***	6.454***
	(0.064)	(0.051)	(0.010)	(0.017)	(0.082)	(0.046)	(0.072)	(0.065)
UNOBHET	0.747***	0.834***	0.746***	0.473***	1.314***	1.410***	1.465***	1.572***
	(0.018)	(0.021)	(0.005)	(0.011)	(0.024)	(0.014)	(0.023)	(0.019)

Table A.8: Multiple-Spell Duration Analysis of Sell Limit Orders of Small-Cap Stocks in the ASX Trade Period (August 2011 Sample)

This table presents the results for the multiple-spell duration survival analysis of sell limit orders of small-cap stocks in the period that the ASX Trade was in operation (August 2011 sample). The table describes the study of limit order dynamics as a sequence of multiple limit order events. The estimation model used in this survival analysis is the Proportional Hazard model under the exponential distribution for limit order times. Definitions of the explanatory variables are given in the text. Panel A reports the results for limit order executions (including full and partial), limit order revisions and limit order cancellations that followed a limit order submission. Panel B reports the results for the limit order events that followed a limit order revision and Panel C reports the results for the limit order events that followed a limit order partial execution. The coefficient estimates are presented for each of the variable and the standard errors are reported in the parentheses. ***, **, * denote statistical significance at the 1, 5 and 10 percent level respectively.

Panel A

ORIGIN	**Submission**			
DESTINATION	***Full Execution***	***Partial Execution***	***Revision***	***Cancellation***
PRICEGAP	-0.104***	-0.028***	0.237***	0.151***
	(0.023)	(0.011)	(0.024)	(0.008)
INITRADE	-0.118***	-0.023***	-0.060***	-0.007**
	(0.015)	(0.008)	(0.006)	(0.003)
SSLIQUIDITY	-2.772***	-1.369***	-0.763***	-0.606***
	(0.016)	(0.011)	(0.020)	(0.007)
MKDPR	0.885***	0.832***	-0.626***	-0.386***
	(0.022)	(0.038)	(0.024)	(0.007)
OSLIQUIDITY	0.212***	0.108***	-0.220***	0.062***
	(0.015)	(0.010)	(0.009)	(0.004)
ORDSIZE	0.271***	0.089***	-0.223***	-0.096***
	(0.024)	(0.011)	(0.012)	(0.006)
CONST	3.100***	-0.057***	0.417***	0.751***
	(0.017)	(0.009)	(0.008)	(0.004)
UNOBHET	0.699***	-0.101***	0.028***	0.205***
	(0.010)	(0.010)	(0.008)	(0.004)

Panel B

ORIGIN	**Revision**				**Partial Execution**			
DESTINATION	***Full Execution***	***Partial Execution***	***Revision***	***Cancellation***	***Full Execution***	***Partial Execution***	***Revision***	***Cancellation***
PRICEGAP	-0.700***	-0.096***	-0.789***	0.058***	-0.126***	-1.024***	-0.383***	-1.145***
	(0.063)	(0.019)	(0.013)	(0.019)	(0.023)	(0.041)	(0.083)	(0.093)
INITRADE	-0.199***	-0.056***	0.147***	0.086***	0.389***	0.674***	0.218***	0.418***
	(0.031)	(0.013)	(0.006)	(0.013)	(0.019)	(0.037)	(0.069)	(0.067)
SSLIQUIDITY	-1.929***	-1.506***	0.318***	-0.263***	-1.274***	-2.062***	-1.429***	-1.080***
	(0.043)	(0.024)	(0.009)	(0.018)	(0.027)	(0.049)	(0.080)	(0.079)
MKDPR	0.645***	0.336***	-0.099***	-1.898***	0.009	0.042	0.411***	0.029
	(0.030)	(0.013)	(0.008)	(0.024)	(0.013)	(0.031)	(0.064)	(0.053)
OSLIQUIDITY	0.381***	0.179***	0.570***	-0.137***	-0.043*	0.386***	0.750***	0.090
	(0.035)	(0.015)	(0.009)	(0.018)	(0.024)	(0.039)	(0.064)	(0.064)
ORDSIZE	1.062***	0.221***	1.344***	-0.096***	0.259***	1.812***	1.060***	1.860***
	(0.068)	(0.020)	(0.010)	(0.019)	(0.024)	(0.046)	(0.093)	(0.093)
PREVDUR	-0.009***	-0.010***	-0.009***	-0.024***	-0.002***	-0.004***	0.004	-0.010***
	(0.001)	(0.001)	(<.001)	(0.001)	(<.001)	(0.001)	(0.003)	(0.002)
CONST	3.630***	1.178***	4.406***	1.965***	5.419***	6.794***	5.950***	6.080***
	(0.039)	(0.018)	(0.007)	(0.016)	(0.025)	(0.035)	(0.069)	(0.067)
UNOBHET	0.979***	0.037**	0.914***	0.517***	1.359***	1.501***	1.450***	1.550***
	(0.017)	(0.015)	(0.003)	(0.011)	(0.007)	(0.010)	(0.022)	(0.020)