The impact of new information upon UK financial futures markets.

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The Impact of New Information Upon UK Financial Futures Markets

by

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Thesis

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To My Parents

Declaration

This work has not previously been accepted in substance for any degree and is not being concurrently submitted in candidature for any degree.

Anna Elizabeth Radcliffe
December 2003

Statement

This thesis is the result of my own investigation, except where acknowledgement of other sources is given.

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Summary

There is little published evidence on the reactions of UK financial futures prices and associated trading activity to new information. This thesis addresses this deficiency in the literature by focusing on two forms of information exposure in UK futures markets. These occur in the form of either a repo rate announcement or from information inferred from observing the historical pattern of transactions. This study examines the impact of the unexpected component of repo rate announcements on futures markets. We find that the size of the price reaction and the amount of associated trading activity following an announcement was generally explained by the degree of surprise. This study also examines the information content of trade arrival times, or trade durations in market microstructure. In particular we generalise Hasbrouck's VAR model, to determine the role played by trade durations in the price formation process and the autocorrelations of trades. We find that a buy transaction arriving after a long time interval has a lower price impact than a buy transaction arriving right after a previous trade. In addition, we model these trade durations using an autoregressive conditional duration (ACD) model. Although we find both the exponential and the Weibull distributions only partially account for the intertemporal correlations present in our duration data, we reject the exponential in favour of the Weibull. We also introduce a new asymmetric log-ACD model, where the next expected duration depends on the trade sign process.

Acknowledgements

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ANNA ELIZABETH RADCLIFFE

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Chapter One

Introduction

Central to the literature concerned with market microstructure is the belief that in a market with asymmetrically informed agents trades convey information, and by examining the characteristics of trades one can infer something about the degree of information in the market. This new information can either arrive in the form of a macroeconomic announcement or by simply observing the historic pattern of trades.

While the literature dedicated to the impact of new information upon financial markets is now extensive, most of these studies consider US data, so it still remains that relatively little empirical work exists on the very high frequency adjustment dynamics exhibited by UK futures markets in response to new information. Since US equity markets open for trading after the release time for economic data, previous US studies have been unable to examine the immediate price adjustment in equity futures markets. It follows that a major innovation of UK studies is that since UK markets open before the release time of economic data, this facilitates an examination of the immediate impact of news announcements upon both futures prices and trading activity. Also the transactions data considered in this study include all transaction prices, whereas in previous US studies of a similar field they only consider price change transactions. The problem with studies using price change transactions is that, this exhibits spurious negative correlation as prices bounce between the bid and ask, and hence offers limited insights into the dynamics of price adjustment to new information.

A second important distinction between UK and US studies rests on the different trading systems used in both markets. In particular, major US markets are specialist markets where a designated market maker provides liquidity by posting bid and ask quotes. However the UK futures markets are now order driven, where there is no market maker but only traders who can enter either limit orders or market orders. A limit order is an order to buy/sell a given quantity at a maximum/minimum price within a given time horizon. A market order is an order to buy/sell a given quantity at the best available price. In an order driven market transactions occur when orders are matched, and the spread amounts to the difference between the smallest limit sell price and the largest limit buy price. Indeed the traders who enter limit orders provide liquidity to those who enter market orders, in a similar manner to market makers providing liquidity in a quote driven market. It follows that since relatively little empirical work exists on the dynamics of price formation in an order driven market, this thesis addresses this deficiency and provides further insights into both price and trade dynamics in an order driven market, and illuminates the similarities and differences of price formation and trade intensity between order driven and specialist markets.

In chapters two and three we examine the impact of repo rate announcements upon price and trading activity of both the Short Sterling and the FTSE 100 futures contracts traded on LIFFE (London International Financial Futures and Options Exchange). Although there exists an extensive literature dedicated to the impact of new information upon financial markets, much of this literature compares the response of prices following an announcement with some non-announcement benchmark. However, if markets are efficient financial prices should only react to the unexpected component of any announcement. While some studies have utilised survey data in an attempt to capture the unexpected component of an announcement, the measure prevalent in most of these studies is the difference between the forecast value and the actual announced value.

However utilising survey data supplied by Reuters, about market participants forecasts of a forthcoming repo rate announcement, we indicate that this difference fails to distinguish between what is entirely expected and entirely unexpected information. This study uses additional measures of market surprise, following a repo announcement, that better captures both the nature and the degree of the surprise element.

In chapter two our results indicate that any unexpected change in repo rate leads to a change in price for both contracts. Further the response is found to be asymmetric for both contacts with the larger negative price reaction following an unexpected increase in repo rate compared with an unexpected decrease. In addition, trading volume was generally associated with a surprise in repo rate for the FTSE 100 but not for the Short Sterling. In chapter three our results indicate that following a not-expected repo rate announcement both contracts initially exhibit large price changes, elevated volatility and an increased number of larger trades. Although there does appear to be some evidence of an initial over-reaction for the Short Sterling, the FTSE 100 exhibited a faster adjustment period. While there appeared to be some evidence of an adjustment following an expected announcement we explain this as a consequence of an element of surprise that remained in this measure of the surprise element. This lead to the development of alternative measures that focus on simply the unexpected components associated with each repo announcement. More specifically we examine the proportion of market participants that forecast an announcement either 25 or 50 basis points either side of the actual announcement and the impact these surprises have upon trade volume and its components, namely trade frequency and trade size. Our results indicate that with most surprised market participants being 25 basis points around the decision, they explain most abnormal trading activity following an announcement.

In chapter four we generalise the VAR model suggested by Hasbrouck (1991) for the dynamics of both trades and quote revisions of the FTSE 100 futures contract. In particular we include time-of-day effects and the time lapse between two consecutive transactions (trade durations). Trade durations have only recently been considered to play a prominent informational role in market microstructure. We aim to extend this recently developed literature that considers a role for time and more importantly to determine the role of time in the price formation process of an order driven market. We uncover both similar and different features of the price formation process of an order driven market compared with a specialist market. Our results indicate that both trade durations and daily periodicities are informative variables in price and trade dynamics of the FTSE 100 futures contract. In consensus with Dufour and Engle (2000) we find that a buy transaction arriving after a long time period has a lower price impact than a buy transaction arriving immediately following a previous trade. In contrast to their findings we show that when quotes are revised in an upward fashion more buyers enter the market and similarly when quotes are revised in a downward fashion more sellers enter the market. Finally in contrast with Dufour and Engle (2000), we find trade durations appear to be robust in the presence of both volume and spread, and therefore we can be confident of our inferences about the role played by trade durations in the dynamics of price formation in an order driven market.

Chapter five uses an autoregressive conditional duration (ACD) framework similar to the one first proposed by Engle and Russell (1998) to address a number of issues regarding the trade intensity process. This ACD framework accounts for the irregular spacing characteristic of transactions data. In the original model, the conditional distribution is assumed to be Weibull, which collapses to the exponential in a particular case. Using FTSE 100 futures contract transactions durations' data we proceed in a similar manner to Engle and Russell (1998) and provide a comparative analysis of both the exponential and the Weibull versions of the ACD model. Our results indicate that both the exponential and the Weibull only partially account for the intertemporal correlations between durations. Similar to Engle and Russell (1998) we prefer the Weibull to the exponential. Secondly we extend the asymmetric Log-ACD model first proposed by Bauwens and Giot (2002) to allow the duration process to depend upon the state of the trade sign process. That is, to examine if when a buyer initiates a trade whether the parameters differ from those if a seller initiates a trade. We also include volume and spread into our version of the asymmetric Log-ACD model and find that both higher volume and spread lead to a shorter time arrival for the next trade.

The findings of this thesis are summarised in chapter six, where conclusions are then drawn on the work as a whole.

Chapter Two

Impact of Repo Rate Announcements upon Futures Markets

This chapter examines the impact of repo rate announcements upon both the Short Sterling interest rate futures and the FTSE100 stock index futures contracts, which are traded on the London International Financial Futures and Options Exchange (LIFFE). We focus on many aspects of market activity, including price changes, price volatility and trading volume. A major innovation in this study is the use of survey data on market participants' expectations, including information on the proportion of the market that correctly forecasted the repo rate decision. We utilise this survey data as a proxy for both the size and the direction of the surprise element. In anticipation of our results, we found that any unexpected change in repo rate leads to a change in price for both the Short Sterling and the FTSE100 futures contracts. In addition, the response in these two markets was found to be asymmetric, with unexpected increases exhibiting the larger price reaction. In general trading volume was not found to be associated with any surprise in repo rate for the Short Sterling however for the FTSE 100 volume was found to be significantly elevated following a surprise announcement. Moreover for the FTSE 100 the response in volume was found to be asymmetric with unexpected increases exhibiting the larger volume reaction. Finally, both markets exhibited a negative relationship between the degree of market consensus of the repo rate decision and price volatility.

2.1 Introduction

The method by which news is impounded into financial markets has always been of great concern and has generally received widespread attention. However only recently, with the availability of high frequency data sets, have researchers from both the academic and financial world been able to examine the high frequency dynamics by which financial market adjusts to new information.

The Efficient Market Hypothesis (E.M.H), as developed by Fama (1970), is one of the main theories in the financial literature. Fama (1970) stated that financial markets are assumed to be informational efficient, and financial market participants form expectations before an announcement on the foundation of all available information. That information should be incorporated in the prices of financial assets prior to any announcement. Thus only the unexpected component of any announcement generates a market adjustment. The availability of survey data on market participants' expectations permits the decomposition of announcements into both expected and not expected components [1].

In this chapter, we employ survey data on market participants' expectations of the forthcoming repo rate decision, as a proxy for the surprise element of each announcement. We proceed with a methodology similar to that of Sun and Sutcliffe (2003) and divide the unexpected announcements into unexpected increases and unexpected decreases. This provides information on both the size and direction of the surprise element. As an additional measure of the surprise element, we utilise information on the proportion of the market that correctly forecast the repo rate

[1] For each announcement the mean forecast of the repo rate was subtracted from the actual decision rate, (see Jain (1988) and Becker et al. (1996)).

decision. We interpret this as, the greater the consensus the smaller the surprise, and similarly the smaller the consensus the greater the surprise.

There exists a burgeoning empirical literature that is devoted to the adjustment of financial markets to new information. The literature focuses on many aspects of the adjustment process, and raises many interesting questions. One such question we explore in this chapter is 'whether investors react in a rational manner to major unanticipated announcements'. We address this question by examining certain aspects of market activity such as price changes, price volatility and trading volume around the announcement time.

2.2 Previous Empirical Literature

This chapter focuses on the role played by price, trading volume and price volatility of both the FTSE100 and the Short Sterling futures contracts in response to a repo rate announcement. Since the empirical literature dedicated to the response of these three market variables to new information is considerable, this section is divided into three main discussions. Firstly the reaction of financial prices to new information, secondly the role played by trading volume in the reaction to new information, and finally the role of volatility in response to new information.

2.2.1 The Reaction of Financial Prices to New Information

An extensive empirical literature examines the effect of 'news' on price adjustments in financial markets. The reaction of financial prices to news should be determined by the magnitude to which the news changes market opinion about the future payoff of the relevant security. Many studies have examined and postulated the impact of unexpected changes in economic variables on stock prices. Sun and Sutcliffe (2003) examined the impact of the scheduled MPC and other macroeconomic announcement surprises on the spot, futures and options market for UK short-term interest rates. They found both the spot and futures market to react strongly to surprises in the repo rate. In addition they found the response of these two markets to repo rate surprises to be asymmetric, with a larger negative reaction for positive surprises. They raised two possibilities for this apparent under-response; the first being that the expected change in repo rate is now expected at either of the next two MPC meetings, or because expectations became more accurate in the seven days between being collected and the MPC meeting. In particular they found the reactions of the spot and futures market to be fully consistent with semi-strong market efficiency.

Others studies have examined how macroeconomic news affects either U.S. bond or equity price movements (Roley and Troll (1983); Jain (1988); Hardouvelis (1988); Smirlock (1986); Urich and Wachtel (1984)). However these studies generally utilise market closing prices, thus they are not concerned with market efficiency or the speed of adjustment, but rather whether any effect exists upon the direction and size of asset price changes. However Jain (1988) is an exception since he considered hourly returns of the S&P 500 index, and concluded that the results were consistent with market efficiency. Two important announcement surprises have a significant negative effect on stock prices, the money-supply announcement and the CPI announcement (Fama and Schwert (1977); Schwert (1981); and Jain (1988)). Becker et al. (1996) provided an analysis of the bond futures market and although they found the markets response to be inefficient, they concluded that there were no logical explanations for why the market failed to promptly exploit all available information. However they raised the possibility of biased expectations leading to spurious response patterns. Cornell (1983) and Sheehan (1985) examined the impact of weekly money stock announcements and concluded that only unexpected announcements influenced financial variables. It has been firmly established that unanticipated increases in money supply lead to immediate increases in interest rates, (Grossman (1981); Roley (1982); Urich and Wachtel (1981)). Schirm et al. (1989) used both investors' expectations and a time series model to measure expected Treasury debt announcements. They used models similar to those documented in Cornell (1983) and Sheehan (1985), and concluded that unexpected Treasury debt announcements prompted no interest rate response. In particular only cash management announcements had any significant effect on interest rates.

2.2.2 The Reaction of Trading Volume to New Information

Beaver (1968) was the first to suggest using volume as a measure of investors' reactions to the release of information. He argued that volume, in conjunction with price changes, reflects two things: a lack of consensus about how a newly disclosed piece of (public) information should be interpreted and the extent to which that information changes individual investors' expectations. Intrinsically, trading volume reflects the sum of differences in traders' reactions, while the change in price reflects only the marginal reaction.

A number of analytical papers have examined the role of information on the volume of trade using different models, (Admati (1985); Bamber and Cheon (1995); Diamond and Verrecchia (1981); Hellwig (1980); Holthausen and Verrecchia (1990); Jain (1988); Kandel and Pearson (1995), Karpoff (1986) and Kim and Verrecchia (1991a)). The underlying notion prevalent in all these models is that most trades in financial markets occur due to differential beliefs.

The notion that differential interpretations are an important stimulus for speculative trading is longstanding. Louis Bacheliers' (1900) seminal thesis on price fluctuations, published more than a century ago hypothesised that:

> *'past, present and even discounted future events are reflected in market price, but often show no apparent relation to price changes . . .*
>
> *Contradictory opinions concerning these changes diverge so much that at the same instant buyers believe in a price increase and sellers in a price decrease'.*

Differential belief revision around public announcements can arise from either differential interpretation of news or a difference in the precision of investors' pre-disclosure information. Differential interpretations of news can cause investors' to revise their beliefs differentially. However, even when the news is commonly interpreted, differences in the precision of pre-disclosure information can cause investors to revise their beliefs differentially because investors will weight commonly interpreted news differently when revising their beliefs.

Kyle (1985) and Admati and Pfleiderer (1988) suggest that informed traders are more active when liquidity trading is high enough to help camouflage their trades. This camouflage reduces the effect of informed trades on prices, thereby increasing the profitability of informed trades. When trading volume is higher than normal, there is more likely to be enough liquidity trading to prompt informed traders to act on their differential interpretations.

Thus if the unexpected component in economic announcements induces divergent beliefs, then there should be increased trading activity in the market following a surprise announcement, as market participants rebalance their portfolios based on the new information. Kandel and Pearson (1995) argued that in the absence of any price change, there is little reason for information based trading other than differential interpretations. However if market participants agree on the effects of new information, they may not engage in additional trading; that is, the observed abnormal volume will be insignificantly different from zero, even if a change in price occurs. This framework allows us to interpret the extent of consensus among traders by examining trading volume in the market. In contrast Verrecchia (1981) believed that the link between information and volume is ambiguous.

Jain et al (1988) found trading volume not to be associated with surprises in the announcements of money supply, the CPI, PPI, unemployment rate, and industrial production. They concluded, that these results are consistent with the hypothesis that market participants interpret the surprises in announcements in an analogous manner and thus do not participate in any additional trading. Woodruff and Senchack (1988) found volume and trade frequency to be abnormally high after the release of the earnings surprise, and although volume remained elevated for some time, trade frequency peaked quickly in the first half-hour and rapidly declined thereafter. In general trade volume, trade frequency and trade size were all seen to be directly associated with the absolute degree of surprise. Kim and Verrechia (1991a) concluded that post-announcement volume is a function of the absolute price change accompanying the announcement and the extent to which the precision of information changes across traders who are heterogeneously informed. Foster and Viswanathan (1993) construct a model that relates unexpected news to higher trading volume and volatility as a result of trading between informed and liquidity traders.

Finally, numerous studies have shown that trading volume associated with an equity price increase is greater than that associated with a price decrease. Epps (1975) and Copeland (1976) explain this by the disparity of opinions held by optimistic and pessimistic investors.

2.2.3 The Reaction of Price Volatility to New Information

There has been increasing concern over the presence of volatility in securities markets. This has stimulated much research into the process by which, new information is impounded into stock prices. Under the uncertain information hypothesis, Brown, et al. (1988) suggest that stock return variability will increase following the announcement of any major unanticipated event as the market responds to the incomplete information concerning the event. As mentioned earlier Foster and Viswanathan (1993) and Sun and Sutcliffe (2003) found volatility to be related to unexpected news. Li and Engle (1995) found the unexpected component of scheduled macro-economic announcements to affect returns and return volatility of US Treasury bond futures. Patell and Wolfson (1984) and Jennings and Starks (1985) observe that following earnings and dividend announcements volatility remained higher than normal for several hours and even into the next day. Ederington and Lee (1995) found volatility to remain greater than normal, even though the major adjustment to the initial release has occurred. They concluded that these continued price fluctuations were the result of either portfolio readjustment by market participants who disagreed with the markets evaluation of the releases implication, or alternatively the release of further information. Crain and Lee (1995) also found volatility to remain higher than normal for several hours, even though most of the price adjustment occurred within the first hour of the announcement.

2.3 Data and Methodology

2.3.1 Monetary Policy Committee (MPC)

On the 6th May 1997[2], the Chancellor of the Exchequer, Gordan Brown announced that the Government was giving the Bank of England operational responsibility for setting interest rates. The Bank of England Act (1998), which gave the Bank that responsibility, came into force on the 1st June 1998. The mechanism chosen to determine interest rates was to set up the MPC. The Bank's monetary policy objective is to deliver price stability (as defined by the Government's inflation target) and, without prejudice to that objective, support the Government's economic policy, including its objectives for growth and employment.

The repo rate[3], which is the interest rate implicit in the prices at which the Bank of England is prepared to buy assets from a bank and then sell them back to the same bank approximately two weeks later. This rate sets the minimum cost of short-term bank funds and, to the extent that any change in the repo rate is not absorbed by a change in the mark-up charged by banks to their customers, directly affects short-term interest rates. Decisions are made by a vote of the Committee on a one-person one-vote basis, with the Governor having the casting vote if there is no majority. Since the MPC meet monthly, their decisions determine the repo rate for the following month. The minutes of

[2] Prior to this date, the Chancellor of the Exchequer, made interest rate decisions, after a monthly meeting with the Bank of England. An important distinction between these two regimes is that during the earlier regime, only interest rate changes were announced and these were unscheduled. However since the MPC has been established, all decisions are announced at 12:00GMT on the Thursday following the first Monday of the month. In addition since the MPC has been established, publicly available macro-economic data has helped the market form an expectation of the forthcoming repo rate, hence survey data of market participants' expectations has become available.

[3] A repo or "sale and repurchase agreement" can apply to Sterling treasury bills, UK government foreign currency debt, eligible bank and local authority bills, specific Sterling bonds issued by supranational organisations and by governments in the European Economic Area, (Monetary Policy Committee, 1999).

the meeting, including a record of any vote, are normally published on the second Wednesday after the meeting. Additionally a change in repo rate may also affect long-term interest rates via its effect on expectations of future short-term rates.

2.3.2 LIFFE Data

The tick-by-tick futures contract data used in this chapter are provided by LIFFE for the FTSE100 and Short Sterling futures contracts traded on this exchange between 7 May 1997 and 30 April 2001. These are two of the most heavily traded contracts on LIFFE. The tick-by-tick data contains details of all trades in the contracts, and gives the time to the nearest second, the price and the number of contracts traded.

The data used are generally for the most heavily traded contract. For the Short Sterling contract the nearest-to-maturity contract is used at all times. For the FTSE100 contracts, we use the nearest-to-maturity contract until the trading volume on the next contract becomes greater. This generally occurs at maturity.

Since the futures price is linked by an arbitrage condition to the spot value of the index, the move to a new contract has virtually no implications for this study. Therefore we pay no attention to contract changeovers in what follows. The close link between futures prices and the price of the underlying asset means that the results will be a good indicator of the reaction of the underlying asset to repo rate surprises.

2.3.3 Environmental Changes

During our sample period, there were two major environmental changes. These were namely, the change in tick size for the FTSE100 and the migration to the electronic trading system from the traditional open outcry. The change in tick size for the FTSE100 occurred in 1998 with the July contract being the first contract to be traded using the new tick size. The switch to electronic trading occurred on the 10^{th} May 1999 for the FTSE100 and the 6^{th} September for the Short Sterling. Figures 2.1 and 2.4 present the daily trade volume around these environmental changes for both the Short Sterling and the FTSE 100 respectively. Figures 2.2 and 2.5 present the daily trade frequency around these environmental changes for both the Short Sterling and the FTSE 100 respectively. Finally, Figures 2.3 and 2.6 present the daily trade size around these environmental changes for both the Short Sterling and the FTSE 100 respectively. We account for the impact of these environmental changes upon market activity, by the addition of two dummy variables representing the change in tick size of the FTSE100 and the switch to electronic trading for both contracts in our model estimations.

2.3.3.1 Tick-Change

Our results clearly indicate that there is a jump in both mean daily trade volume and mean daily trade size after the tick change for the FTSE100. However this change appeared to have no effect upon mean daily trade frequency of the FTSE 100.

2.3.3.2 Electronic Trading System

In recent years we have witnessed many international derivatives exchanges converting from the traditional open outcry to an electronic trading system, these include LIFFE during 1998 to 2000, France's MATIF in June 1998 and the Sydney Futures Exchange in 1999.

Although electronic trading systems are viewed by the exchanges as a means of competing more effectively and boosting trading volume, recently there has been a growing debate on the merits of the electronic system over the traditional open outcry.

Many studies have examined market activity around the transition time, in an attempt to draw some useful conclusions about the impact of the switch to the electronic trading on market activity. Tse and Zabotina (2001) found narrower bid-ask spreads and reduced price clustering in the FTSE100 stock index futures contract following the transition to electronic trading at LIFFE. However in contrast, Ap Gwilym and Evamena (2003) examined the UK long-term government bond futures at LIFFE before and after the transition. They concluded that although price clustering is not greatly affected by the migration to electronic trading, there is a greatly increased concentration of large trades at more popular prices. They also found that mean daily trading volume increased after the transition, though this was not statistically significant. However mean daily trade size dramatically reduced, and the mean daily number of transactions and quotations increased. Finally they reported much elevated volatility since automation. We examine market activity around these environmental changes in an attempt to draw some useful conclusions ourselves. In particular we examine daily trade volume, daily trade frequency and daily trade size of both the Short Sterling and the FTSE 100 and conclude that while mean daily trade volume increases after the switch to electronic trading for the Short Sterling, there is no clear evidence of an impact of the switch to electronic trading on mean daily trading volume for the FTSE100. The reason for there being no observable impact upon volume for the FTSE 100, is because the switch to electronic trading led to both an increase in mean daily trade frequency and a decrease in mean daily trade size for the FTSE 100. It follows from the relationship of trade volume = trade frequency * trade size, that these two effects will offset each other leading to no change in trading volume. For the Short Sterling contract mean daily trade frequency increased and mean daily trade size increased slightly after the switch to electronic trading.

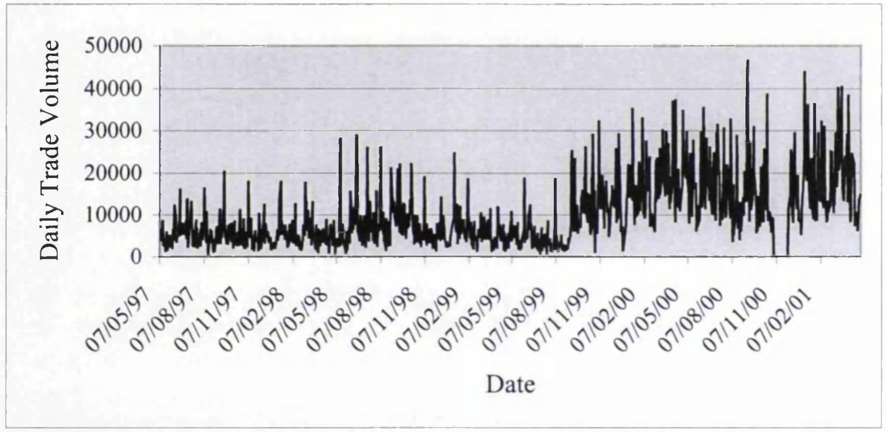

Figure 2.1: Daily Trade Volume of the Short Sterling

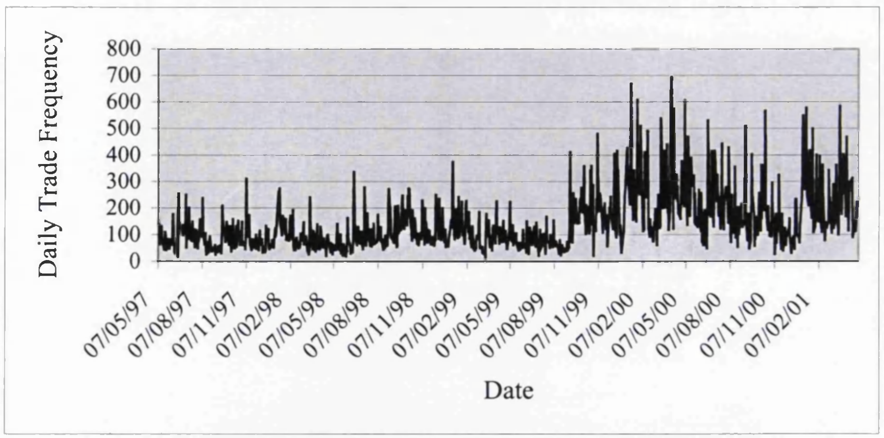

Figure 2.2: Daily Trade Frequency of the Short Sterling

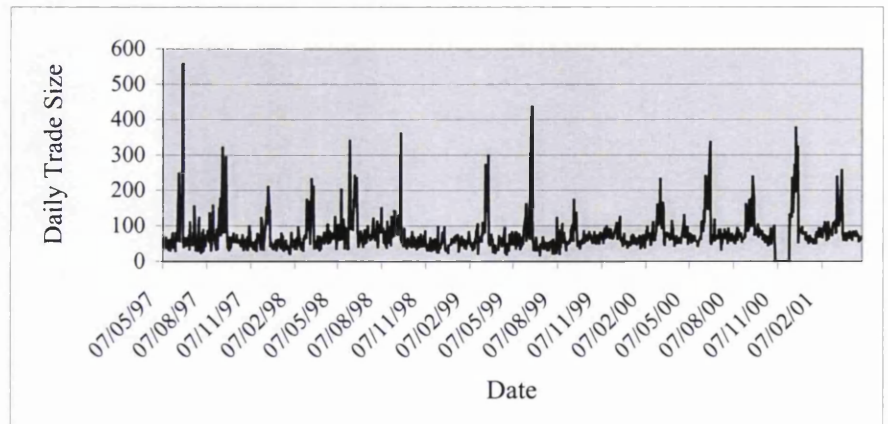

Figure 2.3: Daily Trade Size of the Short Sterling

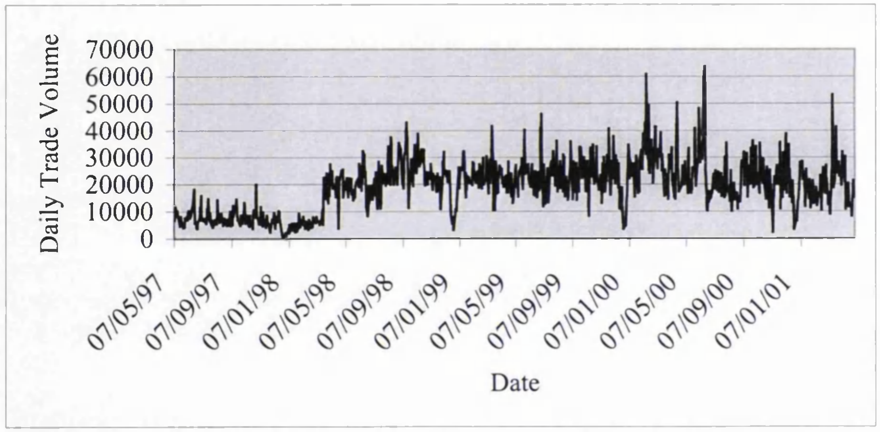

Figure 2.4: Daily Trade Volume of the FTSE 100.

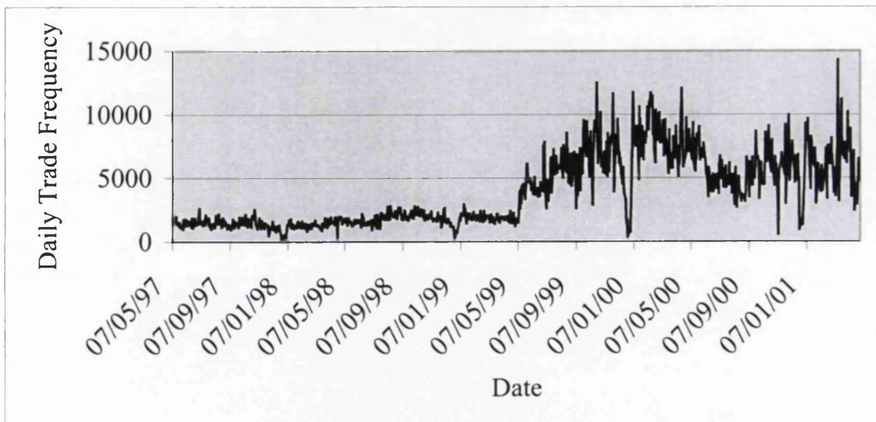

Figure 2.5: Daily Trade Frequency of the FTSE 100.

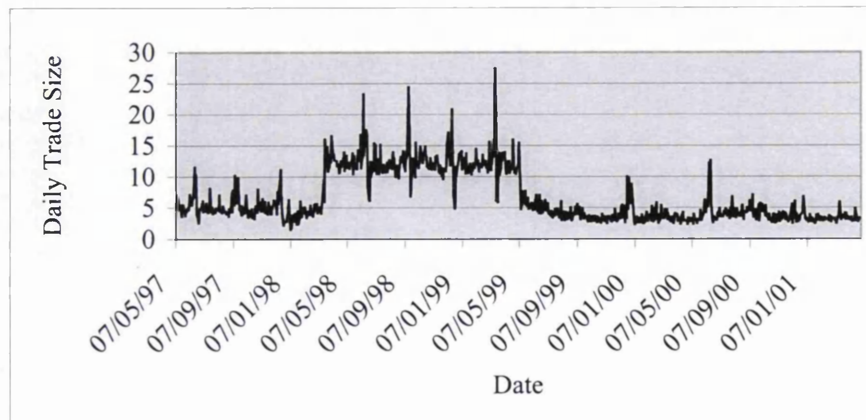

Figure 2.6: Daily Trade Size of the FTSE 100.

2.3.4 Repo Rate Survey Data

Reuters provided the repo rate announcement data, shown in Table 2.1 Reuters conduct a monthly e-mail survey, of the repo rate expectations of about 40 to 50 financial institutions, on the Tuesday and Wednesday of the week preceding the scheduled MPC meeting. Reuters aim for a reply of at least 25 financial institutions. Reuters publish these forecasts at 12:30GMT on the Thursday before the announcement. Table 2.1 shows each monthly repo rate announcement between June 1997 and April 2001. For each month the data provides information on the decision, including whether this decision was a rise, a fall or a no change, the market forecast and the vote of the MPC members. July 1998 marked the arrival of extra information; this represented the proportion of the market that correctly forecast the repo rate decision.

Announcement Date	MPC Decision		MPC Vote	Market Consensus	
	Rate	Change		Forecast	Proportion
Jun 1997	6.50	0.25	6 – 0	0.25	
Jul 1997	6.75	0.25	6 – 0	0.25	
Aug 1997	7.00	0.25	5 – 0	0.25	
Sep 1997	7.00	0.00	7 – 0	0.00	
Oct 1997	7.00	0.00	7 – 0	0.00	
Nov 1997	7.25	0.25	7 – 0	0.00	
Dec 1997	7.25	0.00	8 – 0	0.00	
Jan 1998	7.25	0.00	5 – 3	0.00	
Feb 1998	7.25	0.00	4 – 4	0.00	
Mar 1998	7.25	0.00	4 – 4	0.00	
Apr 1998	7.25	0.00	5 – 3	0.00	
May 1998	7.25	0.00	6 – 2	0.00	
Jun 1998	7.50	0.25	8 – 1	0.00	
Jul 1998	7.50	0.00	9 – 0	0.00	60
Aug 1998	7.50	0.00	7 – 2	0.00	55
Sep 1998	7.50	0.00	7 – 2	0.00	80
Oct 1998	7.25	-0.25	7 – 2	0.00	60
Nov 1998	6.75	-0.50	8 – 1	-0.25	75
Dec 1998	6.25	-0.50	8 – 1	-0.25	80
Jan 1999	6.00	-0.25	7 – 2	0.00	60
Feb 1999	5.50	-0.50	8 – 1	-0.25	60
Mar 1999	5.50	0.00	8 – 1	0.00	60
Apr 1999	5.25	-0.25	8 – 1	-0.25	70
May 1999	5.25	0.00	5 – 4	0.00	70
Jun 1999	5.00	-0.25	8 – 1	0.00	60
Jul 1999	5.00	0.00	9 – 0	0.00	80
Aug 1999	5.00	0.00	9 – 0	0.00	80
Sep 1999	5.25	0.25	7 – 2	0.00	80
Oct 1999	5.25	0.00	9 – 0	0.00	60
Nov 1999	5.50	0.25	8 - 1	0.25	70
Dec 1999	5.50	0.00	6 – 3	0.00	80
Jan 2000	5.75	0.25	8 – 1	0.25	70
Feb 2000	6.00	0.25	8 – 1	0.25	80
Mar 2000	6.00	0.00	9 – 0	0.00	80
Apr 2000	6.00	0.00	6 – 3	0.00	60
May 2000	6.00	0.00	9 – 0	0.25	60
Jun 2000	6.00	0.00	6 – 3	0.00	70
Jul 2000	6.00	0.00	9 – 0	0.00	80
Aug 2000	6.00	0.00	5 – 4	0.00	60
Sep 2000	6.00	0.00	5 – 4	0.00	55
Oct 2000	6.00	0.00	9 – 0	0.00	70
Nov 2000	6.00	0.00	9 – 0	0.00	80
Dec 2000	6.00	0.00	7 – 2	0.00	85
Jan 2001	6.00	0.00	5 – 4	0.00	70
Feb 2001	5.75	-0.25	9 – 0	-0.25	70
Mar 2001	5.75	0.00	7 – 2	0.00	70
Apr 2001	5.50	-0.25	6 - 3	-0.25	60

Table 2.1: Results of Reuters Monthly Repo Rate Survey Data

2.4 Empirical Results

2.4.1 Bias and Efficiency Tests

Due to several days elapsing between the date of the survey and the date of the repo rate decision, it is possible that intervening events may lead to a systematic revision in forecasts, which destroys the information value of the news estimated as the difference between the decision and the forecast. In addition, market participants may in fact alter their forecast opinions to be in line with the market majority.

To investigate this matter, we follow a similar methodology to Balduzzi et al. (1998) and Anderson et al. (2002) [4].

We regress the actual announcement, A_i on the mean forecast of the survey F_i, and the change in the futures price between the time of the survey and the time of the repo rate announcement, Δy:

$$A_i = \alpha_{0,i} + \alpha_{1,i} F_{i,t} + \alpha_{2,i} \Delta y_t + e_{i,t}, \tag{2.1}$$

This regression facilitates the testing of several hypotheses. Firstly, if there is information content in the survey data, the coefficient estimates $\alpha_{1,i}$ should be positive and significant. Secondly if the survey information is unbiased, the coefficient estimates $\alpha_{0,i}$ should be insignificant and the slope term $\alpha_{1,i}$ should be insignificantly different from unity. Finally, if expectations are revised between the survey and the announcement, there should be a reaction in the futures price at the time of the revision, and we should see a relationship between the change in the futures price and the announcement.

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[4] Balduzzi et al. (2001) find most of the MMS forecasts contain information and are unbiased. They also find that for most indicators the hypothesis that $\alpha_{2,i} = 0$ cannot be rejected. Hence the MMS forecasts do not appear significantly stale.

	Short Sterling			FTSE100		
	Coefficient	T-statistic	Probability	Coefficient	T-statistic	Probability
$\alpha_{0,i}$	-0.038	-0.296	0.769	-0.001	-0.008	0.994
$\alpha_{1,i}$	1.004	48.568	0.000	0.998	45.558	0.000
$\alpha_{2,i}$	-0.007	-2.177	0.035	-0.001	-0.092	0.927

Table 2.2: Bias Test

Coefficient estimates, *t*-statistics and associated probabilities for Equation (2.1),

$$A_i = \alpha_{0,i} + \alpha_{1,i} F_{i,t} + \alpha_{2,i} \Delta y_t + e_{i,t}$$

The dependent variable, A_i is the actual repo rate announcement. The explanatory variables are the mean forecast of the survey, F_i and the change in the futures price between the time of the survey and the repo rate announcement, Δy. Number of observations = 47.

The results in Table 2.2 indicate that the repo rate forecasts contain information and are unbiased. In addition, for the FTSE100 we cannot reject the hypothesis that $\alpha_{2,i} = 0$, but we can for the Short Sterling. This indicates that while the forecasts do not appear to be significantly stale for the FTSE100, there does appear to be some evidence for the Short Sterling of a market revision between the time of the survey and the announcement. In the analyses of this chapter we account for any market revision by including an explanatory variable that measures market activity during the week preceding the announcement, i.e. between the forecast release and the actual announcement. For this purpose we calculate the change in price, between the time of the survey release and the announcement [5].

[5] Although we used other measures of market activity, including average daily price changes, average daily volatility and average daily trading volume, in the week preceding the announcement, these provided no additional information to that provided by the change in price between the time of the survey and the time of the announcement, and hence had no implication on the coefficients or *t*-statistics of other explanatory variables. We therefore do not report the results using other measure of market activity.

As a further investigation of the validity of the forecasts, we perform an efficiency test of the forecasts. To comply with the principle of rational expectations and thus be useful in an analysis of market efficiency, the forecasts need to be both unbiased and efficient. While we have shown our forecasts to be unbiased, we shall perform an efficiency test similar to Pearce and Roley (1985) and Becker et al. (1996) [6].

In the efficiency test, the surprise value S_i (actual release value minus the forecast value) for each series is regressed on lagged release values of the series, and the joint hypothesis of zero lag coefficients is tested.

$$S_i = \alpha_0 + \alpha_1 lag1 + \alpha_2 lag2 + \alpha_3 lag3 + e_i, \qquad (2.2)$$

The underlying idea is that if the announced data, is generated by an autoregressive process, the markets expectation should be generated by the same process. As a result, the current surprise should be independent of the lagged announced values.

[6] Pearce and Roley (1985) and Becker et al. (1996), previously performed bias and efficiency tests for the MMS forecasts. Pearce and Roley (1985) find that the MMS survey estimates are unbiased (with the exception of industrial production) and efficient over the time period of their study and conclude that the survey data is more accurate than autoregressive models by virtue of lower mean squared errors. Becker et al. (1996) find four out of the nine forecasts considered in their study to be both unbiased and efficient, these include CPI, merchandise trade, nonfarm payrolls and housing starts.

	Coefficient	T-statistic	Probability
α_0	0.113	0.847	0.402
α_1	0.141	1.342	0.187
α_2	0.015	0.083	0.934
α_3	-0.176	-1.713	0.094

Table 2.3: Efficiency Test

Coefficient estimates, *t*-statistics and associated probabilities for Equation (2.2),

$$S_i = \alpha_0 + \alpha_1 lag1 + \alpha_2 lag2 + \alpha_3 lag3 + e_i$$

The dependent variable S_i is the surprise value. The explanatory variables are the three lags of the actual release values. Number of observations= 44.

The results in Table 2.3 indicate that we cannot reject the hypothesis that $\alpha_1 = \alpha_2 = \alpha_3 = 0$. Thus we can conclude that the current surprise is independent of the lagged announcements, hence we declare the forecasts to be efficient.

2.4.2 The Effect of Repo Rate Announcements upon Futures Prices

2.4.2.1 Hypothesis

For the Short Sterling, we predict that any unexpected change in repo rate is predicted to lead to a similar effect on the rate of return implicit in the price of the Short Sterling futures, i.e. $\beta_1 = \beta_2 = -1$ (*Hypothesis* 1)[7].

For the FTSE100, we predict a negative relationship exists between any unexpected changes in repo rate and the price of the FTSE100 futures contract (*Hypothesis* 2)[8]. In addition we predict that the relationship between the FTSE100 futures price and any unexpected change in repo rate to be asymmetric, with unexpected increases in the repo rate exhibiting the larger price reaction (*Hypothesis 3)*[9].

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[7] By convention interest rate futures are quoted as 100(1-R_F), where R_F is the annual futures spot return implicit in the current price of the Short Sterling future. Therefore an increase in R_F of 1% corresponds to a decrease in F of 1%, and so the repo rate is expected to have a negative effect on the futures' price.

[8] Repo rate decreases are recognised as beneficial to UK companies and hence the economy. This is because the cost of borrowing becomes cheaper. Hence if the repo rate decision was an unexpected decrease, then the FTSE100 is expected to rise. Similarly an unexpected increase in repo rate should lead to a fall in the FTSE100.

[9] It is generally considered that markets react far greater response to negative news than positive news, (Anderson et al. (2002), Sun and Sutcliffe (2003)). Woodruff and Senchack (1988) found the most unfavourable earnings surprise corresponded with the largest price adjustment. Following the "up-stick" rule, which states that it is more difficult to short a stock on unfavourable news than to buy on favourable news, they found the most favourable earnings stocks had the quickest adjustment.

2.4.2.2 The Model

The impact of unexpected changes in the repo rate upon the futures price is examined by estimating the following linear regression equation:

$$\Delta F_t = \alpha_0 + \beta_1 U\Delta MPC_t^+ + \beta_2 U\Delta MPC_t^- + \beta_3 D_1 + \beta_4 D_2 + \beta_5 \Delta P_t + e_i, \tag{2.3}$$

where ΔF_t=change in futures price from the last trade before the announcement to the end of the first five, fifteen and sixty minutes of trading after the announcement[10]. The economic variables include unexpected increases in the repo rate $U\Delta MPC_t^+$ and unexpected decreases in the repo rate $U\Delta MPC_t^-$ [11]. The two dummy variables D_1 and D_2 are defined where $D_1 = 1$ if announcement occurs after the FTSE100 changed tick size and zero otherwise. $D_2 = 1$ if announcement occurs after the introduction of electronic trading and zero otherwise. The economic variable ΔP_t is defined as the change in futures price from the time the survey is released to the last trade before the announcement.

[10] We examine the change in price over different time intervals to establish, both the magnitude and direction of the price adjustment, for both the short and long run, in response to the release of new information into the market.

[11] An unexpected increase in the repo rate is defined as the announced repo rate exceeding the expected repo rate. Similarly an unexpected decrease in the repo rate is defined as the announced repo rate being lower than the expected repo rate.

2.4.2.3 The Results

		Short Sterling			FTSE100		
		Coefficient	T-statistic	Probability	Coefficient	T-statistic	Probability
5 min	α_0	0.006	0.549	0.586	3.511	1.697***	0.098
	β_1	-0.659	-5.963*	0.000	-136.060	-8.881*	0.000
	β_2	-0.379	-4.535*	0.000	-55.633	-1.368	0.179
	β_3	-	-	-	-6.908	-1.235	0.224
	β_4	0.005	0.361	0.720	1.094	0.188	0.852
	β_5	-0.004	-3.004*	0.005	0.014	0.764	0.449
15 min	α_0	0.006	0.502	0.619	5.578	1.218	0.231
	β_1	-0.677	-5.713*	0.000	-166.440	-5.099*	0.000
	β_2	-0.390	-4.349*	0.000	-1.846	-0.073	0.942
	β_3	-	-	-	-9.554	-1.555	0.128
	β_4	0.003	0.202	0.841	3.717	0.752	0.457
	β_5	-0.005	-3.186	0.003	0.025	1.559	0.127
60 min	α_0	0.009	0.829	0.412	2.033	0.242	0.810
	β_1	-0.808	-6.769*	0.000	-161.156	-2.695*	0.010
	β_2	-0.360	-3.989*	0.000	71.483	1.539	0.132
	β_3	-	-	-	-14.910	-1.324	0.193
	β_4	0.001	0.071	0.943	3.917	0.432	0.668
	β_5	-0.004	-2.472**	0.018	0.051	1.735***	0.091

Table 2.4: Effects of Unexpected Changes in Repo Rate upon Futures Price

Coefficient estimates, *t*-statistics and associated probabilities for Equation (2.3),

$$\Delta F_t = \alpha_0 + \beta_1 U\Delta MPC_t^+ + \beta_2 U\Delta MPC_t^- + \beta_3 D_1 + \beta_4 D_2 + \beta_5 \Delta P_t + e_i$$

The dependent variable is the change in futures price (ΔF_t) from the last trade before the repo rate announcement to the end of the first five, fifteen and sixty minutes of trading after the announcement. $U\Delta MPC_t^+$ represents the unexpected increases in repo rate, $U\Delta MPC_t^-$ represents the unexpected decreases in repo rate, D_1 is a dummy variable representing the change in tick-size for the FTSE 100. D_2 is a dummy variable representing the switch to the electronic trading system. ΔP_t, represents the change in future price between the survey release and the announcement, * = Significant at 1% level. ** = Significant at the 5% level. *** = Significant at the 10% level. Number of observations=47.

Short Sterling: White Heteroskedasticity Test Statistics: 5 minutes, 4.689 (probability = 0.455), 15 minutes, 4.003 (probability = 0.549), 60 minutes, 2.214 (probability = 0.819).
LM Test for Serial Correlation Test Statistics: 5 minutes, 0.061 (probability = 0.970), 15 minutes, 0.126 (probability = 0.939), 60 minutes, 0.540 (probability = 0.763).
Jacque-Bera Test for Normality Test Statistics: 5 minutes, 4.827 (probability = 0.090), 15 minutes, 9.239 (probability = 0.010), 60 minutes, 1.396 (probability = 0.498).
Adjusted R^2 values: 5 minutes = 0.563, 15 minutes = 0.544, 60 minutes = 0.585.

FTSE100: White Heteroskedasticity Test Statistics: 5 minutes, - (probability = -), 15 minutes, 7.433 (probability = 0.283), 60 minutes, 5.454 (probability = 0.487).
LM Test for Serial Correlation Test Statistics: 5 minutes, 4.423 (probability = 0.120), 15 minutes, 3.963 (probability = 0.138), 60 minutes, 2.937 (probability = 0.230).
Jacque-Bera Test for Normality Test Statistics: 5 minutes, 5.637 (probability=0.060), 15 minutes, 0.570 (probability = 0.752), 60 minutes, 7.446 (probability = 0.024).
Adjusted R^2 values: 5 minutes = 0.342, 15 minutes = 0.364, 60 minutes = 0.172.

The results in Table 2.4 indicate that unexpected increases in the repo rate have a larger negative effect on the price of both the Short Sterling and the FTSE100 futures contracts than do unexpected decreases. For the Short Sterling this difference is not significant over the first five and fifteen minutes of trading, but is significantly different (at the 5% level) over the first sixty minutes of trading[12, 13]. For the FTSE100 this difference is not significant over the first five and sixty minutes of trading, but is significantly different (at the 1% level) over the first fifteen minutes of trading. For the Short Sterling the values of both β_1 and β_2 are significantly different to minus one[14]. However, as post-announcement time increases, β_1 tends to minus one. This suggests that after 60 minutes, the market is approaching the new price equilibrium. In addition α_0 is close to zero indicating that when the decision is expected, the market does not exhibit any price adjustment. For the FTSE100 the results indicate that unexpected decreases did not appear to have a significant effect upon futures price. Finally the change in futures price between the time of the survey release and the announcement is found to have a significantly negative effect upon the price of the Short Sterling only. This is consistent with the earlier results shown in Section (2.4.1) of a market revision between the time of the survey release and the announcement for the Short Sterling only.

In conclusion hypothesis 1 is rejected for both unexpected increases and decreases. We partially accept hypothesis 2 as our results were only found to be significant for unexpected increases. We accept hypothesis 3 that for the relationship between changes

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[12] Sun and Sutcliffe (2003) found the coefficient for positive MPC surprises to be significantly different from the coefficient for negative surprises on both LIBOR and Short Sterling futures.

[13] To establish whether or not the two independent variables are significantly different, we examine their confidence intervals. If they do overlap then they are not significantly different. However if these do not overlap, then they are significantly different. These confidence intervals are constructed as:
coefficient $\pm$ (standard error) * z_α ,
where z_α corresponds to the test statistic of the significance level of $100*\alpha\%$.

[14] Sun and Sutcliffe (2003) found apart from positive surprises upon Short Sterling futures, the effect of MPC surprises on LIBOR and Short Sterling futures is less than one.

in the FTSE100 index and unexpected changes in repo rate, was stronger for unexpected increases than decreases.

For the Short Sterling estimation, the White heteroskedasticity test, the LM test, and the Jacque-Bera test of the residuals indicate that there is no heteroskedasticity or serial correlation, however there does appear to be evidence of non-normality (p=0.01) present for 15 minutes only. Hence we can be confident of our inferences for both the 5 minutes and 60 minutes. For the FTSE100, the White Heteroskedasticity test, the LM test and the Jacque-Bera test of the residuals indicate that there is no serial correlation, however heteroskedasticity is present for 5 minutes only, and non-normality is present (p=0.024) for 60 minutes only. Therefore for the five minutes regression we report White Heteroskedastic Consistent Standard Errors. Hence we can be confident of our inferences for both the five and fifteen minutes. However, econometric sources such as Kmenta (1971), suggested that non-normal disturbances are common in small data sets and so this limitation is an unavoidable constraint of the research design.

2.4.3 The Effect of Repo Rate Announcements upon Futures Trading Volume.

2.4.3.1 Hypotheses

Any unexpected change in repo rate, whether this be an unexpected increase or an unexpected decrease is predicted to lead to an increase in trading volume of both the Short Sterling and the FTSE 100 futures contracts (*Hypothesis 4*).

Trading volume of the FTSE 100 is predicted to be higher following unexpected decreases in repo rate compared with unexpected increases in repo rate (*Hypothesis 5*)[15],[16].

[15] An unexpected decrease in repo rate leads to a price increase in the FTSE 100 futures contract.

[16] Numerous studies have shown that trading volume associated with an equity price increase is greater than that associated with a price decrease (Epps (1975); Copeland (1976)).

2.4.3.2 The Model

The impact of unexpected changes in the repo rate upon trading volume of the futures contracts is examined by estimating the following linear regression equation:

$$\ln V_t = \alpha_0 + \beta_1 U\Delta MPC_t^+ + \beta_2 U\Delta MPC_t^- + \beta_3 D_1 + \beta_4 D_2 + e_i, \tag{2.4}$$

where $\ln V_t$ = natural logged trading volume of the futures contracts between the time of the announcement and the first five minutes of trading after the announcement[17]. The two economic variables are unexpected increases in the repo rate ($U\Delta MPC_t^+$) and unexpected decreases in the repo rate ($U\Delta MPC_t^-$). The two dummy variables, D_1 and D_2 are defined where D_1=1 if the announcement occurred after the tick change for the FTSE100, and zero elsewhere and D_2=1 if the announcement occurred after the switch to electronic trading and zero elsewhere.

[17] We found the trading volume series to be non-normal for both the Short Sterling and the FTSE100 hence we performed these regressions using the natural logs of the volume data series. Regulez and Zarraga (2002) found evidence that volume was non-normal. Others have used the natural logs of volume, these include Ajinkya and Jain (1989), Campbell et al. (1993) and Bamber et al. (1999).

2.4.3.3 The Results

		Short Sterling			FTSE 100		
		Coefficient	T-Statistic	Probability	Coefficient	T-Statistic	Probability
5 min	α_0	5.749	24.247*	0.000	4.504	11.018*	0.000
	β_1	-0.265	-0.103	0.919	3.537	2.679*	0.011
	β_2	-4.027	-2.211**	0.032	-2.384	-3.701*	0.001
	β_3	-	-	-	1.250	3.005*	0.005
	β_4	2.327	7.129*	0.000	-0.044	-0.245	0.808

Table 2.5: Effects of Unexpected Changes in Repo Rate upon Futures Trading Volume

Coefficient estimates, t-statistics and associated probabilities of Equation (2.4),

$$\ln V_t = \alpha_0 + \beta_1 U\Delta MPC_t^+ + \beta_2 U\Delta MPC_t^- + \beta_3 D_1 + \beta_4 D_2 + e_i ,$$

The dependent variable, $\ln V_t$ is the natural logged trading volume of the futures contract between the time of the announcement and the first five minutes of trading after the announcement. $U\Delta MPC_t^+$ represents the unexpected increases in repo rate, $U\Delta MPC_t^-$ represents the unexpected decreases in repo rate, D_1 is a dummy variable representing the change in tick-size for the FTSE 100. D_2 is a dummy variable representing the switch to the electronic trading system. * = Significant at the 1% level. ** = Significant at the 5% level. Number of observations = 47.

Short Sterling: White heteroskedasticity test statistic: 4.717 (probability = 0.194).
LM test for serial correlation test statistic: 0.721 (probability = 0.697).
Jarque-Bera test for normality test statistic: 1.024 (probability = 0.599).
Adjusted R^2 value = 0.513

FTSE100: LM test for serial correlation test statistic: 1.916 (probability = 0.384).
Jarque-Bera test for normality test statistic: 1.925 (probability = 0.382).
Adjusted R2 value = 0.342

The results in Table 2.5 indicate that for the Short Sterling, unexpected decreases in the repo rate lead to an increase in trading volume, however unexpected increases play no part in explaining the dependent variable. For the FTSE100, we found the residuals to show evidence of heteroskedasticity, thus we report White heteroskedastic consistent standard errors. The results for the FTSE 100 contract show both unexpected increases and unexpected decreases play an important part in explaining the elevated abnormal post-announcement volume. In addition, we found this reaction to be greater for unexpected increases than unexpected decreases in repo rate.

Hence for the Short Sterling the results partially support hypothesis 4, as we find elevated volume following an unexpected decrease in repo rate, however we find there to be no relation between unexpected increases in repo rate and post-announcement volume. However, for the FTSE100, the results lead us to accept hypothesis 4 and reject hypothesis 5.

2.4.4 The Effect of Repo Rate Consensus upon Futures Trading Volume

2.4.4.1 Hypothesis

If the unexpected component in the repo rate announcement induces divergent beliefs, there should be an increase in trading activity following an announcement[18]. The relationship between the proportion of the market correctly forecasting the repo rate decision and trading volume is predicted to be negative for both the Short Sterling and the FTSE100 financial futures contracts (*Hypothesis 6*).

2.4.4.2 The Model

The relationship between the proportion of the market correctly forecasting the repo rate decision and the trading volume of the futures contracts is examined by estimating the following linear regression equation.

$$\ln V_t = \alpha_0 + \beta_1 Pb_t + \beta_2 D_2 + e_i \, , \qquad (2.5)$$

where $\ln V_t$ = natural logged values of trading volume of the futures contract between the time of the announcement and the first five minutes of trading after the announcement. The economic variable Pb_t = the proportion of the market that correctly forecast the repo rate decision. The dummy variable D_2 is defined as D_2 = 1, if the announcement day occurred after the switch to the electronic trading system.

[18] See Section 2.2.2.

2.4.4.3 The Results

		Short Sterling			FTSE100		
		Coefficient	T-statistic	Probability	Coefficient	T-statistic	Probability
5 min	α_0	7.054	16.181*	0.000	6.637	22.445*	0.000
	β_1	-0.010	-1.364	0.182	-0.012	-2.218**	0.034
	β_2	1.738	5.038*	0.000	-0.066	-0.259	0.797

Table 2.6: Effect of Repo Rate Consensus upon Futures Trading Volume.

Coefficient estimates and t-statistics of Equation (2.5),

$$\ln V_t = \alpha_0 + \beta_1 Pb_t + \beta_2 D_2 + e_i \, ,$$

The dependent variable, $\ln V_t$ is the natural logged trading volume of the futures contracts between the time of the announcement and the first five minutes of trading after the announcement. Pb_t represents the proportion of the market that correctly forecast the repo rate decision, D_2 is a dummy variable representing the switch to the electronic trading system. * = significant at the 1% level. ** = significant at the 5% level. Number of observations = 34.

Short Sterling: White heteroskedasticity test statistic: 4.437 (probability = 0.218).
LM test for serial correlation test statistic: 0.388, (probability = 0.824).
Jacque-Bera test for normality test statistic: 0.811, (probability = 0.667).
Adjusted R^2 value = 0.418.

FTSE100: White heteroskedasticity test statistic: 2.548 (probability = 0.467).
LM test for serial correlation: 3.899 (probability = 0.142).
Jacque-Bera test for normality test statistic: 0.382 (probability = 0.826).
Adjusted R^2 value = 0.132.

The results in Table 2.6 indicate that for the Short Sterling, the proportion of the market correctly forecasting the repo rate decision plays no part in explaining post-announcement volume. However for the FTSE100 we found the relationship between the proportion of the market correctly forecasting the repo rate decision and trading volume to be negative (significant at the 5% level). Hence as the proportion of the market correctly forecasting the repo rate decision decreases, volume increases. We conclude therefore that we accept hypothesis 6 for the FTSE100, but not for the Short Sterling.

2.4.5 The Effect of Repo Rate Consensus upon Financial Futures Price Volatility

2.4.5.1Hypothesis

Following the uncertain information hypothesis, (Brown et al. (1988)), we predict the relationship between the proportion of the market correctly forecasting the repo rate decision and price volatility to be negative, (*Hypothesis 7*).

2.4.5.2 The Model

The relationship between the proportion of the market correctly forecasting the repo rate decision and price volatility is examined by estimating the following linear regression equation.

$$AR_t = \alpha_0 + \beta_1 Pb_t + \beta_2 D_2 + \beta_3 \Delta P_t + e_i, \qquad (2.6)$$

where $AR_t = abs(\ln(P_{t+n}/P_{t-n}))$,[19]

P_{t+n} = the price of the last trade over interval $t+n$, where t= time of announcement, and n = 5, 15 and 60 minutes. Pb_t = the proportion of the market forecasting the repo rate decision. The dummy variable D_2 is defined where $D_2 = 1$ if announcement occurs after the switch to electronic trading and zero otherwise. The economic variable ΔP_t = the change in futures price from the time the survey is released to the last trade before the announcement.

[19] All log returns are multiplied by 10^3.

2.4.5.3 The Results

		Short Sterling			FTSE100		
		Coefficient	T-statistic	Probability	Coefficient	T-statistic	Probability
5 min	α_0	15.433	7.585*	0.000	51.218	4.091*	0.000
	β_1	-0.155	-4.663*	0.000	-0.343	-1.734***	0.094
	β_2	-1.537	0.993	0.329	-19.854	-2.271**	0.031
	β_3	-0.130	-0.973	0.339	0.021	0.809	0.425
15 min	α_0	15.960	7.029*	0.000	38.822	3.866*	0.001
	β_1	-0.153	-4.118*	0.000	-0.171	-0.989	0.331
	β_2	-1.930	-1.117	0.273	-12.035	-1.389	0.175
	β_3	-0.161	-1.082	0.288	-0.012	-0.444	0.660
60 min	α_0	15.663	7.168*	0.000	72.053	3.885*	0.001
	β_1	-0.143	-4.002*	0.000	-0.293	-0.915	0.368
	β_2	-2.081	-1.251	0.221	-25.635	-1.602	0.120
	β_3	-0.090	-0.632	0.532	-0.059	-1.151	0.259

Table 2.7: Effect of Repo Rate Consensus upon Futures Price Volatility

Coefficient estimates, t-statistics and associated probabilities of Equation (2.6),

$$AR_t = \alpha_0 + \beta_1 Pb_t + \beta_2 D_2 + \beta_3 \Delta P_t + e_i,$$

The dependent variable, AR_t represents volatility. Pb_t represents the proportion of the market that correctly forecast the repo rate decision, D_2 is a dummy variable representing the switch to the electronic trading system. ΔP_t represents the change in futures price between the time of the survey release and the announcement, * = significant at 1% level. ** = significant at the 5% level. *** = significant at the 10% level. Number of observation = 34.

Short Sterling: White Heteroskedasticity Test Statistics: 5 minutes, 7.874 (probability = 0.163), 15 minutes, 7.697 (probability = 0.174), 60 minutes, 8.721 (probability = 0.121).
LM Test for Serial Correlation Test Statistics: 5 minutes, 0.994 (probability = 0.608), 15 minutes, 0.765 (probability = 0.682), 60 minutes, 1.980 (probability = 0.372).
Jacque-Bera Test for Normality Test Statistics: 5 minutes, 3.552 (probability = 0.169), 15 minutes, 6.553 (probability = 0.038), 60 minutes, 10.786 (probability = 0.005).
Adjusted R^2 Values: 5 minutes, 0.450, 15 minutes, 0.399, 60 minutes, 0.392.

FTSE100: White Heteroskedasticity Test Statistics: 5 minutes, - (probability = -), 15 minutes, 6.773 (probability = 0.238), 60 minutes, 5.037 (probability = 0.411).
LM Test for Serial Correlation Test Statistics: 5 minutes, 2.744 (probability = 0.254), 15 minutes, 0.694 (probability = 0.707), 60 minutes, 2.436 (probability = 0.296).
Jacque-Bera Test for Normality Test Statistics: 5 minutes, 0.716 (probability = 0.699), 15 minutes, 30.371 (probability = 0.000), 60 minutes, 61.944 (probability = 0.000).
Adjusted R^2 Values: 5 minutes, 0.452, 15 minutes, 0.077, 60 minutes, 0.135.

The results in Table 2.7 indicate that a negative relationship exists between the proportion of the market correctly forecasting the repo rate decision and the volatility of both the Short Sterling and the FTSE100 futures contracts. Although volatility remains persistently elevated for the Short Sterling following an unexpected announcement, for the FTSE 100 volatility remains elevated for only 5 minutes. Therefore, we accept hypothesis 7, for both contracts.

For the Short Sterling, the White test, the LM Test, the Jacque-Bera test of the residuals indicate that there is no heteroskedasticity or serial correlation present however there does appear to be evidence of non-normality for both the fifteen and sixty minutes residuals, ($p = 0.038, 0.005$), respectively. For the FTSE100, the White test, the LM test, the Jacque-Bera test of the residuals indicates that there is no serial correlation, however heteroskedasticity is present at the 5 minutes only, hence we report White heteroskedastic consistent standard errors. The Jacque-Bera test indicates strong evidence of non-normality for both the fifteen and sixty minutes residuals. However, as we discussed earlier, Kmenta (1971), suggested that non-normal disturbances are common in small data sets and that this limitation is an unavoidable constraint of the research design.

2.5 Summary and Conclusions

In this chapter we examined the impact of repo rate surprises upon market activity of both the Short Sterling and the FTSE 100 futures contracts. We utilised survey data supplied by Reuters on market participants' expectations of the forthcoming repo rate announcement, as a proxy for both the direction and the magnitude of the surprise element in the market following an announcement. In a similar manner to Sun and Sutcliffe (2003) we used the difference between the forecast value and the actual announced value to determine whether an unexpected announcement was an unexpected increase or an unexpected decrease in repo rate. In addition we used the proportion of the market that correctly forecast the actual announcement as a further indication of the size of the surprise element in the market following an announcement.

Due to the possibility of a market revision between the time of the survey release and the announcement, we performed bias and efficiency tests of the forecasts, and found that while the announcements were efficient, there does appear to be some evidence of a market revision for the Short Sterling only. In our models, we accounted for any market revision by an additional explanatory variable that measures the change in futures price between the time of the survey release and the time of the announcement. As expected this variable was significant in our model of price change for the Short Sterling only.

We also provided evidence of a change in market activity following a tick-change for the FTSE 100 and the transition to the electronic trading system from the traditional open-outcry for both the Short Sterling and the FTSE 100. In our models we accounted for these changes by additional dummy variables and found the change in tick-size to be significant in relation to both volatility and trading volume of the FTSE 100 and the switch to electronic trading to be significant in relation to trading volume of the Short Sterling.

Our results indicate that both markets react strongly to repo rate surprise announcements. Consistent with Sun and Sutcliffe (2003), we found the response in both markets to be asymmetric with unexpected increases causing the larger negative reaction in price. Consistent with the uncertain information hypothesis, (Brown et al. (1988)), we found that volatility became elevated immediately following a surprise announcement. Although this returned to normal levels after only 5 minutes for the FTSE 100, for the Short Sterling volatility remained elevated for at least 60 minutes following a surprise announcement.

In general trading volume was found to be positively associated with the surprise element for the FTSE 100, but not generally for the Short Sterling. This indicates that for the FTSE 100 following a surprise announcement market participants differ in their evaluation of the announcement and therefore rebalance their portfolios based on the new information. In addition, we found the response of the FTSE100 contract to be asymmetric, with unexpected increases in the repo rate leading to a larger volume reaction, compared with unexpected decreases. However for the Short Sterling, our results indicate that although price appeared to react to repo rate surprises, trading volume was generally not found to be associated with our surprise measure. We suggest in a similar manner to Kandel and Pearson (1995) that if market participants agree on the effects of the announcement, then they may not engage in any additional trading, even if a change in price occurs.

Chapter Three

Repo Rate Surprise and the Transaction Process

In the previous chapter, we utilised survey data on market participants' expectations of the forthcoming repo rate to provide an analysis of the impact of repo rate surprises, upon both the FTSE100 stock index and the Short Sterling interest rate futures contracts. We focused on three aspects of market activity including price changes, trading volume and price volatility, and concluded that the response in these two markets was found to be asymmetric, with unexpected increases exhibiting the larger negative price reaction. In addition, we found trading was associated with a surprise in repo rate for the FTSE100 futures contract but not generally for the Short Sterling futures contract. This chapter provides additional insights into the impact of repo rate surprises upon both the Short Sterling futures contract and the FTSE100 futures contract. We focus on many aspects of market activity, including price, trade frequency and trade size. We provide an analysis of the adjustment behaviour, of both futures prices and futures trading volume over both transaction time and 15-second time intervals. Additionally we provide a direct measure of the degree of repo rate surprise, to provide a unique analysis of the impact of repo rate surprises upon trading.

3.1 Introduction

Although there exists a burgeoning empirical literature dedicated to the adjustment of financial markets to new information, relatively little empirical work exists on the dynamics of trade frequency and trade size in response to new information. This chapter addresses this deficiency by examining the effects of repo rate surprises upon both trade frequency and trade size of both the Short Sterling and the FTSE100 futures contracts. In addition, by examining both trade frequency and trade size, we are offering a deeper insight in the response of trade volume to new information[1].

In the previous chapter we established that financial markets should only respond to the unexpected component of any announcement. The analysis supported this by showing that unexpected changes in repo rate lead to a change in price for both the Short Sterling and the FTSE100 futures contracts. In addition, we found trading volume of the FTSE100 futures contract was consistently associated with our measures of repo rate surprise. However for the Short Sterling, trading volume was only associated with an unexpected decrease in repo rate. In the previous chapter we were not concerned with market efficiency or the speed and duration of the adjustment process, but rather with whether any effect exists upon both the direction and the magnitude of both the futures price changes and the futures trading volume. This chapter provides additional insights into both the price adjustment process and the trading associated with the release of repo rate announcements. In particular we decompose our announcements into expected and not-expected components and focus on the speed of price adjustment and the number of transactions to achieve a new equilibrium price.

Most models that assess the impact of new information upon financial market activity, determine the surprise element as the difference between the forecast value and the announced value. In the previous chapter we used this measure in a similar manner to Sun and Sutcliffe (2003) and separated our unexpected announcements into unexpected increases and unexpected decreases in repo rate. For our second measure of the surprise

[1] This follows from equation V=F*S, where V=trade volume, F=trade frequency and S=trade size,

element, we utilised the degree of market consensus relating to the repo rate decision. In this chapter more detailed survey data on market participants' expectations of the forthcoming repo rate announcement is used. More specifically, each surveyed market participant provides a probability of whether there is likely to be no change in the interest rate, or a rise or a fall decision of 25 or 50 basis points. We interpret the means of these probabilities as representative of the proportion of market participants expecting that decision. This provides more detailed information on the views of market participants and hence on the impact of unexpected information upon financial market activity. We proceed by examining the impact of the degree of surprise upon trade volume, trade frequency and trade size. By measuring the trading activity in response to the degree of surprise of market participants we provide a further understanding of the reactions of market participants in response to unexpected information. Further, by examining both trade frequency and trade size, we also provide a deeper understanding of the role played by volume in response to new information.

3.2 Previous Empirical Literature

In recent years we have witnessed an increased availability of high frequency transactions data sets that has generated research on the very high frequency dynamics by which financial markets adjust to new information. The literature devoted to the adjustment process examines important questions such as 'How long does it take for the information to be fully incorporated in market prices, in the sense that price volatility returns to normal levels?' and 'How quickly and efficiently does the market incorporate the new information?' If prices adjust slowly, then based on the markets initial response, traders with quick access to the market may be able to earn excess trading profits. This opportunity for trading profits may end long before volatility has returned to normal levels. Trading profits are only possible if the direction of the futures price changes is predictable, whereas volatility may remain high if subsequent price adjustments are large but unpredictable.

Much of the literature in this area examines the effect of earnings and dividend announcements upon equity prices. Patell and Wolfson (1984) and Jennings and Starks (1985) find that although the return variance remains higher for several hours, the opportunity to earn excess returns ceases after ten to fifteen minutes. In contrast Woodruff and Senchack (1988) and Brown et al. (1992) find that the average time between an unexpected earnings announcement and the first post-announcement trade is fourteen minutes. However they do not test for significance and find that roughly half of the adjustment occurs within the first thirty minutes. Brown et al. (1992) discover that following extremely bad or good earnings news, prices tend to trend in the same direction for approximately four hours. Barclay and Litzenberger (1988) find that profit opportunities last around fifteen to thirty minutes following new issue announcements. Jain (1988) found the response of the S&P 500 index to unexpected changes in money supply and CPI to be completed within one hour. Ederington and Lee (1993) find that volatility in US interest rate and foreign exchange futures markets remains significantly higher than normal for between forty to sixty minutes after scheduled macroeconomic announcements, although the opportunity for trading profits ends within one minute. Ederington and Lee (1995) show that US interest rate and foreign exchange futures markets begin adjusting within the first ten seconds of an announcement and that most of the adjustment to a new equilibrium is complete within forty to fifty seconds. They also found weaker evidence of an overreaction in the first forty seconds with a correction in the second or third minute after an announcement. Leng (1996) shows that the impact of 'major' announcements upon price variability in US foreign exchange futures markets lasts for at least an hour, while the impact of 'minor' announcements is short-lived. Ederington and Lee (1994) examine dollar/yen futures, and find that volatility is higher during the forty-minute period following 8:30EST announcements. They also found price adjustment begins within ten seconds and is complete within fifty seconds, with some evidence of an initial overreaction. Crain and Lee (1995) compare the reaction of spot and futures prices in interest rate and currency markets to scheduled macroeconomic announcements. They found while most price adjustments occur within the first hour following the announcement, volatility remains above normal for several hours in both markets, although longer in the spot market. However as they use hourly intervals in the analysis, they cannot be precise about the duration of the price adjustment. Becker et al. (1996) used MMS expectations data to provide an analysis of the efficiency of bond futures markets, they found the markets response to be inefficient. They concluded that there were no logical explanations for why the market failed to promptly exploit all available information. However they raised the possibility of biased expectations leading to spurious response patterns.

Theoretical models of the price adjustment process, such as Brown and Jennings (1989) and Grundy and McNichols (1989), suggest that uninformed traders can obtain information from observing the sequence of prices during the price adjustment period. The theoretical models of Blume et al. (1994), Diamond and Verrecchia (1987), and Easley and O'Hara (1992) suggest that other aspects of market activity such as volume and the time between trades may offer important insights into the adjustment process.

Although much evidence exists on the role played by trading volume in response to new information (see section 2.2.2), relatively scant evidence exists on the role played by its components. Ap Gwilym et al. (1998) found that both the interest rate and the equity index futures markets reacted immediately to macroeconomic announcements. Although there was an initial overreaction for both markets, the FTSE100 futures price adjusted to the new information within seven transactions. The Short Sterling exhibited a slightly longer adjustment period of around ten transactions. In addition they found smaller trade sizes prior to an announcement release, and suggested that investors are reluctant to trade prior to an announcement. However immediately following an announcement, they found average sized trades for the FTSE100 futures contract while the price adjusted to the new information, with larger trades being delayed until the price had fully adjusted. In contrast the Short Sterling contract exhibited large trades for a considerable time. They concluded that diverging opinions explained the impact of an announcement upon the Short Sterling market.

3.3 Data and Methodology

This chapter presents two main analyses. In our first analysis we follow a similar methodology to Ap Gwilym et al. (1998) to examine the adjustment behaviour of both futures prices and futures trading volume in response to repo rate announcements. However this chapter provides an analysis that differs from Ap Gwilym et al. (1998) in that conditional expectations are used to provide a more accurate analysis of any adjustment process. In particular we use survey data on market participants' expectations of the forthcoming repo rate to decompose our announcements into expected and not-expected components. To determine the market reaction to repo rate announcements we compare measures of market activity around the announcement time with a 'normal' or non-announcement period. In addition we provide a comparative analysis between the reactions following a not-expected announcement with those following an expected announcement. The announcement windows considered here are both transaction time and clock time periods. Focusing on both transaction time and clock time intervals is particularly useful for comparative studies of different markets where trade frequencies are different. We focus on a transaction-by-transaction period that considers the first 30 transactions following an announcement and a clock-time period that extends from two minutes before the announcement to ten minutes after, which we term the announcement window running from T–120 seconds to T+600 seconds. This permits the capture of any activity prior to the repo announcement, and is long enough to examine the adjustment process. The non-announcement benchmark is derived from the same 30 transactions/twelve-minute windows for any Thursday where there was no repo rate information release.

We examine many aspects of the adjustment behaviour of both futures prices and futures volume both transaction-by–transaction and over 15-second time intervals. First we gain insight into the nature of the adjustment process by comparing price volatility, average absolute price changes, average number of transactions and average trade sizes across announcement days with non-announcement days[2]. Second, we investigate the duration of the adjustment process by comparing average percentage continuations across announcement days with non-announcement days. Finally, we investigate the speed of the adjustment process by examining the correction to the new equilibrium price over each time interval. We find that while both price and volume react more strongly following a not-expected announcement compared with following an expected one, there does appear to be some evidence of a reaction following an expected announcement. We interpret these findings as a consequence of the method used to construct the surprise element. More specifically we interpret an expected announcement as one where more than 50 percent of surveyed market participants expected it. This is the standard approach adopted in studies utilising survey data (e.g. Roley and Troll (1983), Urich and Wachtel (1984), Smirlock (1986), Jain (1988), Hardouvelis (1988) and Becker et al. (1996)) and provides a good proxy of whether the anticipated component is greater or smaller than the unanticipated component. However it means that there is still a significant proportion of the market that did not expect the expected decision. Similarly in every not-expected announcement there is an element of anticipated news. Therefore any market adjustment following an expected announcement is the consequence of elevated trading by a minority whose prior expectations were not confirmed in the announcement.

In our second analysis we address this issue and examine the impact of the degree of repo rate surprise upon trading. We proceed by separating our surprise element for each announcement into four different measures of surprise; the proportion of the market that forecast a decision 50 basis points below the decision, 25 basis points below the decision, 25 basis points above the decision and 50 basis points above the decision. In particular we examine the impact of these four measures of repo rate surprise upon trade volume, trade frequency and trade size during the first five minutes after the announcement. By observing the impact of repo rate surprises upon trade frequency and

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[2] Following the impact of the transition to electronic trading from the floor upon market activity, (see Section 2.3.3.2). We divide our analysis of both trade frequency and trade size into the period before electronic trading was introduced and the period after electronic trading was introduced.

trade size, we provide a deeper understanding of the reaction of volume to new information.

3.3.1 LIFFE Data

Again we use tick-by-tick data provided by LIFFE for both the Short Sterling interest rate futures contract and the FTSE100 stock index futures contract traded on this exchange between July 1998 and September 2003. Again, the data used are generally for the most heavily traded contract. For the Short Sterling contract the nearest-to-maturity contract is used at all times. For the FTSE100 contracts, we use the nearest-to-maturity contract until the trading volume on the next contract becomes greater. This generally occurs at maturity.

3.3.2 Repo Rate Survey Data

Reuters provided the repo rate announcement data shown in Table 3.1. As described in chapter two, Reuters conduct a monthly e-mail survey, of the repo rate expectations of about 40 to 50 financial institutions, on the Tuesday and Wednesday of the week preceding the scheduled MPC meeting. Reuters aim for a reply of at least 25 financial institutions. Reuters publish these forecasts at 12:30GMT on the Thursday before the announcement.

However since July 1998, the market participants surveyed by Reuters have provided a more detailed forecast of the forthcoming announcement, incorporating a probability assessment of all feasible repo rate decisions. These decisions range from a fall to a rise of 50 basis points, in incremented steps of 25 basis points. Table 3.1 shows each monthly repo rate announcement between July 1998 and September 2003. For each month the data provides information on the average proportion of market participants that forecast a decision of no change, to a rise or a fall of 25 or 50 basis points, along with the repo decision and the market forecast. We highlight in bold the proportion of surveyed market participants that correctly forecast the repo rate decision. We consider an announcement that was forecasted by at least 50 percent of the surveyed market participants as an expected announcement, and similarly those announcements that were forecasted by less than 50 percent of surveyed market participants as not-expected announcements.

3.3.3 Electronic Trading System

In chapter two (section 2.3.3.2), we indicated that the switch to the electronic trading system from the traditional open outcry caused a change in market activity. In particular trade frequency increased after the switch to the electronic trading system, for both contracts. However for trade size, both contracts reported different patterns following the switch to the electronic trading system. For the FTSE 100 trade size decreased quite substantially. In contrast the Short Sterling contract showed a slight increase in trade size. In the analyses of this chapter we account for the effects on market activity of both contracts following the switch to the electronic trading system. In our first analysis we separate our data sample in to two periods, namely the pre-electronic trading system period (pre-ET) and the post-electronic trading system period (post-ET). In our regression analysis we include a dummy variable, D_t, where D_t assumes a value of one if the announcement occurs after the switch to the electronic trading system and zero elsewhere.

Date	Repo Rate Forecasts					MPC Decision Change	Market Forecast Change
	-50	**-25**	**0**	**25**	**50**		
Jul 1998	0	0.97	**59.44**	39.29	0	0.00	0.00
Aug1998	0	0.97	**59.44**	39.29	0	0.00	0.00
Sep1998	0	13.24	**80.48**	6.29	0	0.00	0.00
Oct 1998	0	**41.33**	58.41	0.26	0	-0.25	0.00
Nov1998	**2.14**	73.57	24.29	0	0	-0.50	-0.25
Dec1998	**11.15**	59.81	29.04	0	0	-0.50	-0.25
Jan 1999	2.39	**38.87**	58.74	0	0	-0.25	0.00
Feb 1999	**5.93**	54.67	39.41	0	0	-0.50	-0.25
Mar1999	0	48.85	**51.15**	0	0	0.00	0.00
Apr1999	1.48	**63.19**	35.33	0	0	-0.25	-0.25
May1999	0	38.78	**61.22**	0	0	0.00	0.00
Jun 1999	0	**37.67**	62.33	0	0	-0.25	0.00
Jul 1999	0	27.05	**72.95**	0	0	0.00	0.00
Aug1999	0	12.62	**81.54**	6.19	0	0.00	0.00
Sep 1999	0	4.31	76.54	**18.96**	0	0.25	0.00
Oct 1999	0	0.97	**62.68**	36.36	0	0.00	0.00
Nov1999	0	0.71	34.42	**59.84**	4.03	0.25	0.25
Dec1999	0	0.17	**71.86**	27.97	0	0.00	0.00
Jan 2000	0	0	30.76	**66.21**	3.03	0.25	0.25
Feb 2000	0	0.03	27.50	**69.53**	2.94	0.25	0.25
Mar2000	0	0.28	**71.11**	28.61	0	0.00	0.00
Apr 2000	0	0	**58.11**	41.89	0	0.00	0.00
May2000	0	0	**40.32**	59.68	0	0.00	0.25
Jun 2000	0	0	**67.72**	31.72	0	0.00	0.00
Jul 2000	0	0.33	**75.60**	24.07	0	0.00	0.00
Aug2000	0	0.63	**59.37**	40.00	0	0.00	0.00
Sep 2000	0	0.32	**55.13**	44.71	0	0.00	0.00
Oct 2000	0	0.15	**69.37**	30.45	0	0.00	0.00
Nov2000	0	1.25	**78.38**	20.37	0	0.00	0.00
Dec2000	0	6.67	**83.97**	9.36	0	0.00	0.00
Jan 2001	0	24.94	**74.31**	0.75	0	0.00	0.00
Feb 2001	2.93	**62.03**	34.93	0.07	0	-0.25	-0.25
Mar2001	0	35	**64.83**	0.17	0	0.00	0.00
Apr 2001	0	**52.17**	47.83	0	0	-0.25	-0.25
May2001	0	**70.19**	29.62	0.39	0	-0.25	-0.25
Jun 2001	0	29.24	**70.61**	0.15	0	0.00	0.00
Jul 2001	0	14.17	**79.17**	6.67	0	0.00	0.00
Aug2001	0	**14.77**	80.77	4.46	0	-0.25	0.00
Sep 2001	0	19.82	**78.75**	1.43	0	0.00	0.00
Oct 2001	1.80	**53**	44.96	0.24	0	-0.25	-0.25
Nov2001	**3.97**	62.21	33.79	0.03	0	-0.50	-0.25
Dec2001	0	31.70	**68.15**	0.19	0	0.00	0.00
Jan 2002	1.04	21.71	**75.18**	2.14	0.04	0.00	0.00
Feb 2002	0	5.24	**72.76**	21.48	0.52	0.00	0.00
Mar2002	0.02	11.80	**79.64**	8.52	0.02	0.00	0.00
Apr 2002	0.60	3.40	**80.80**	14.80	0.40	0.00	0.00
May2002	0	1.48	**82.19**	15.63	0.70	0.00	0.00
Jun 2002	0	0.29	**67.32**	31.32	1.07	0.00	0.00
Jul 2002	0	0	**77.92**	21.6	0.24	0.00	0.00
Aug2002	0.35	8.58	**83.39**	7.48	0.19	0.00	0.00
Sep 2002	0.97	10.39	**84.71**	3.81	1.03	0.00	0.00

Table 3.1: Results of Reuters Monthly Repo Rate Survey Data.

Bold format indicates the proportion of the market that correctly forecast the repo rate decision.

3.4 Empirical Results

3.4.1 The Price and Volume Adjustment Process

3.4.1.1 The Nature of the Adjustment Process

First we gain insight into the nature of the adjustment process by examining price volatility, the mean value of absolute price changes, the mean number of transactions and mean trade sizes. We compare the behaviour of both the not-expected announcement days and the expected announcement days with the pattern of our non-announcement days. In addition, following the E.M.H. that prices in financial markets should only react to the unexpected component of any announcement indicates that there should be no price reaction following an expected announcement. There exists an extensive empirical literature indicating that volatility increases with the release of new information (See Section 2.2.3). We calculate the standard deviations of returns across 15-second intervals for the announcement window. Figures 3.1 and 3.2 show the volatility of the Short Sterling futures contract and the FTSE100 futures contract around the announcement time respectively. These clearly indicate a sharp increase in volatility following a repo rate announcement. Although generally the unexpected announcements show a much higher volatility in comparison with the expected announcement days, there still appears to be abnormally high volatility following an expected announcement. This indicates that while the majority of market participants forecast the announcement decision a minority of those were still surprised by the announcement. This leads to higher than normal trading following an expected announcement. In addition there appears to be evidence of a market readjustment for the Short Sterling. This appears to occur within the second minute after the announcement. Prior to the announcement volatility generally appears to higher across announcement days in comparison with non-announcement days. This indicates market uncertainty, and a lack of consensus about the announcement.

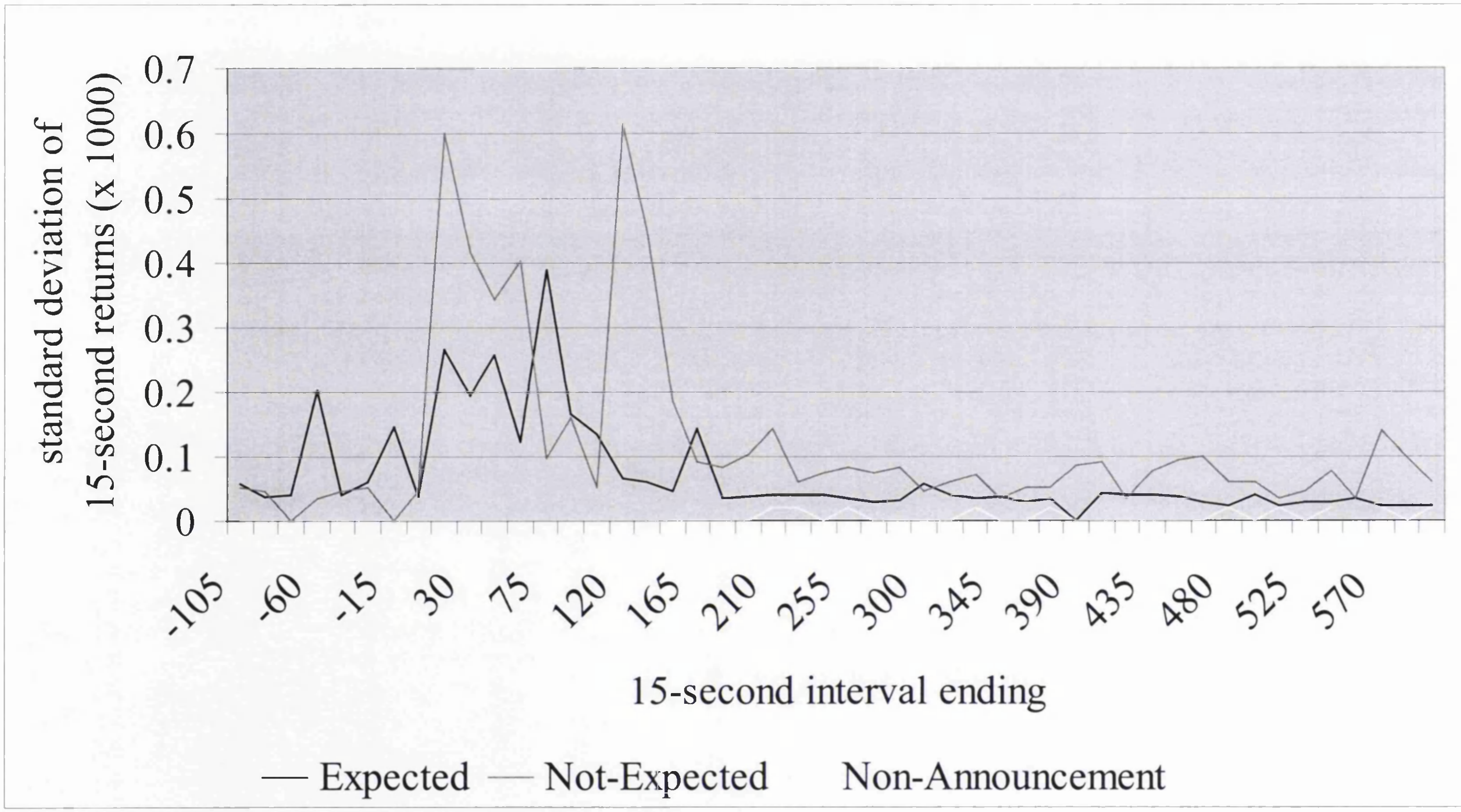

Figure 3.1: Volatility of the Short Sterling Around Repo Rate Announcement

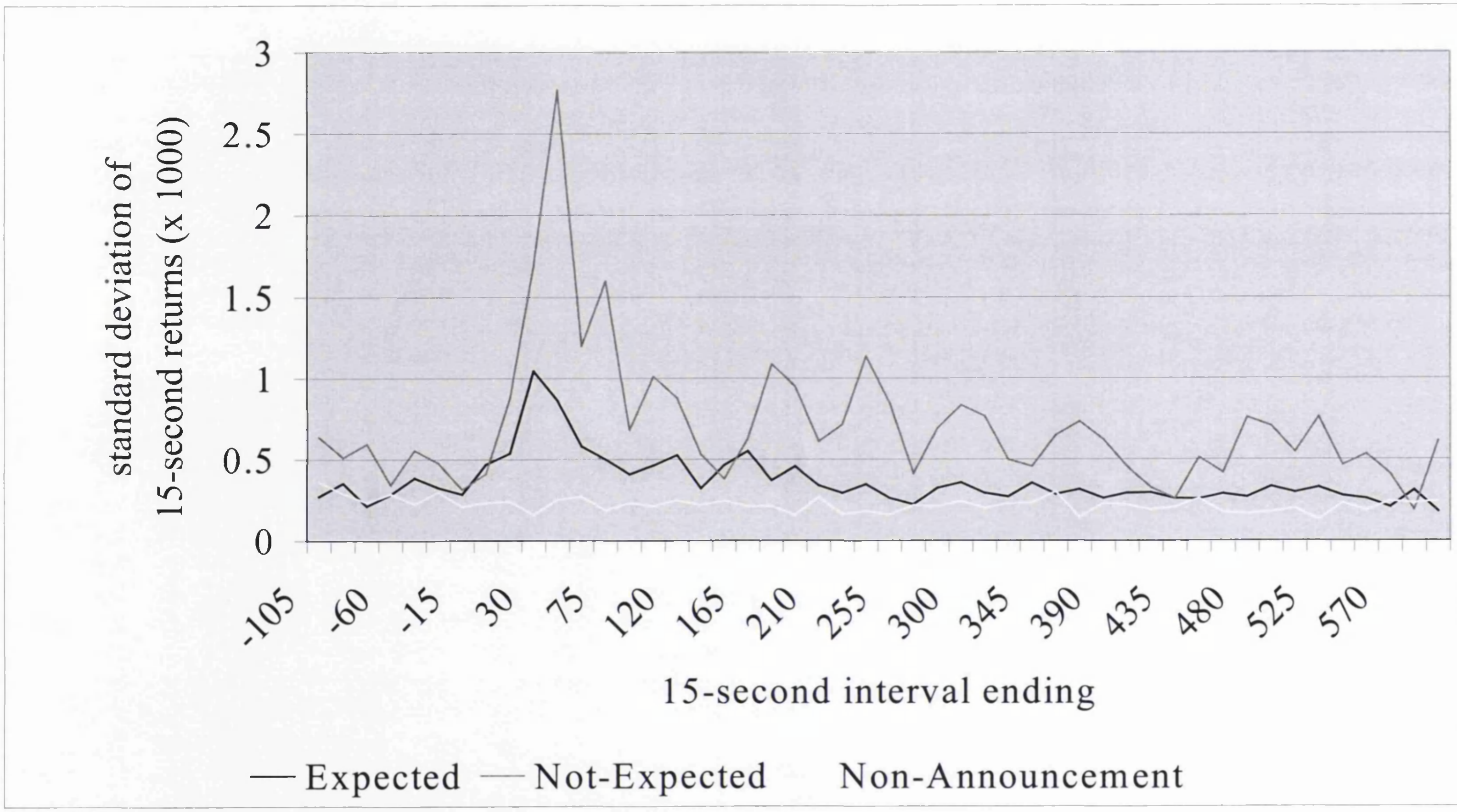

Figure 3.2: Volatility of the FTSE 100 Around Repo Rate Announcement

Next, we examine the mean absolute price changes around a repo rate announcement, this provides an alternative measure of volatility. Table 3.2 presents the mean absolute price change per transaction following a repo rate announcement. Our results indicate that both contracts react immediately to the announcement. The mean absolute price change by transaction, following a not-expected announcement, remain significantly greater than both the non-announcement period and the respective expected announcement transaction period for the remainder of the 30 transactions. However, there is evidence for both contracts of a price reaction following an expected announcement. While the mean absolute price change by transaction following an expected announcement remains larger than the non-announcement period for at least 30 transactions, these are only significant for around the first 14 transactions for the Short Sterling compared with around 7 transactions for the FTSE100.

Table 3.3 presents the mean absolute price changes around a repo rate announcement measured over clock-time. Our results indicate that prior to the announcement the mean absolute price changes remain larger than the non-announcement period for both contracts. This is particularly true for the FTSE100, where the mean absolute price changes prior to a not-expected announcement are significantly greater than both the respective expected announcement period and the non-announcement period. Following an announcement, both contracts begin reacting to the news within fifteen seconds. The mean absolute price changes are initially large. During the first 30 seconds both contracts exhibit a mean absolute price change following a not-expected announcement of twice as large as the respective expected announcement period. The mean absolute price changes then decline rapidly after 60 seconds for the Short Sterling with a market readjustment occurring after around 120 seconds, and around 75 seconds for the FTSE100 following a not-expected announcement. The mean absolute price changes for not-expected announcements then remain significantly greater than both the respective expected announcement period and the non-announcement period for at least 10 minutes for both contracts. Following an expected announcement, although the mean absolute price change declines rapidly after around 75 seconds for the Short Sterling and 60 seconds for the FTSE100, there are some later significant intervals. Finally, it is interesting to note that following an expected/not-expected announcement our results are indicative of a shorter/longer price adjustment period than that found in Ap Gwilym et al. (1998). This suggests that as the majority of the price adjustment is the consequence of any unexpected components of an announcement, then the price adjustment following an announcement will appear to be shorter in the Ap Gwylim study due to the expected component of that announcement.

	Short Sterling		**FTSE100**	
Non-Announcement	**0.22**		**0.65**	
Transaction Number	**E**	**NE**	**E**	**NE**
1	0.73^{a}	1.00$^{a,\mathbf{a}}$	1.65^{b}	2.45$^{a,\mathbf{a}}$
2	1.05^{a}	2.80$^{a,\mathbf{a}}$	1.55^{b}	6.35$^{a,\mathbf{a}}$
3	0.66^{b}	1.80$^{a,\mathbf{a}}$	1.96^{a}	3.45$^{a,\mathbf{a}}$
4	0.61^{b}	1.80$^{a,\mathbf{a}}$	1.02	2.75$^{a,\mathbf{a}}$
5	0.51^{b}	1.10$^{a,\mathbf{a}}$	1.41^{b}	2.50$^{a,\mathbf{b}}$
6	0.41	0.70$^{a,\mathbf{a}}$	1.09	1.50$^{a,\mathbf{a}}$
7	0.56^{b}	1.30$^{a,\mathbf{b}}$	1.45^{b}	7.15$^{a,\mathbf{a}}$
8	0.54^{b}	0.70$^{a,\mathbf{b}}$	0.94	2.95$^{a,\mathbf{a}}$
9	0.63^{b}	1.10$^{a,\mathbf{b}}$	1.11	1.95$^{a,\mathbf{a}}$
10	0.46^{b}	1.00$^{a,\mathbf{b}}$	1.13	2.30$^{a,\mathbf{a}}$
11	0.37	0.90$^{a,\mathbf{a}}$	1.22	3.05$^{a,\mathbf{a}}$
12	0.54^{b}	0.70$^{a,\mathbf{b}}$	1.40^{b}	2.95$^{a,\mathbf{b}}$
13	0.24	1.30$^{a,\mathbf{a}}$	1.26	2.80$^{a,\mathbf{a}}$
14	0.46^{a}	1.10$^{a,\mathbf{b}}$	1.17	1.60$^{a,\mathbf{a}}$
15	0.32	1.00$^{a,\mathbf{a}}$	1.40	2.45$^{a,\mathbf{a}}$
16	0.29	0.70$^{a,\mathbf{a}}$	1.46^{b}	1.89$^{a,\mathbf{b}}$
17	0.27	0.80$^{a,\mathbf{a}}$	0.87	1.40$^{b,\mathbf{b}}$
18	0.34	0.70$^{a,\mathbf{a}}$	0.70	2.60$^{a,\mathbf{a}}$
19	0.27	0.50$^{a,\mathbf{b}}$	1.11	1.80$^{a,\mathbf{a}}$
20	0.27	0.30	1.01	1.75$^{a,\mathbf{a}}$
21	0.29	0.40^{b}	0.83	2.05$^{a,\mathbf{a}}$
22	0.34	0.50$^{a,\mathbf{b}}$	0.91	2.15$^{a,\mathbf{a}}$
23	0.27	0.80$^{a,\mathbf{a}}$	1.06	2.95$^{a,\mathbf{a}}$
24	0.34	0.90$^{a,\mathbf{a}}$	0.85	1.10
25	0.46^{b}	0.50^{a}	0.89	2.10$^{a,\mathbf{a}}$
26	0.22	0.50$^{a,\mathbf{a}}$	1.02	2.05$^{a,\mathbf{a}}$
27	0.15	0.40$^{b,\mathbf{b}}$	1.21	1.50
28	0.20	0.50$^{a,\mathbf{a}}$	1.04	2.25$^{a,\mathbf{a}}$
29	0.27	0.80$^{a,\mathbf{a}}$	1.12	2.40$^{a,\mathbf{a}}$
30	0.24	0.30	0.87	1.80^{a}

Table 3.2: Mean Absolute Price Change Across Transactions Following a Repo Rate Announcement.

a/b = the difference between the announcement and the non-announcement is significant at the 1%/5% level.
a/b = the difference between the not-expected announcement and the expected announcement is significant at the 1%/5% level.
E/NE represents expected/not-expected announcements.

	Short Sterling		FTSE100	
Non-Announcement	0.05		0.74	
Time Interval	**E**	**NE**	**E**	**NE**
T - 105	0.22[b]	0.31[a]	0.84	2.70[b, **b**]
T - 90	0.12	0.25	1.05	2.80[a, **a**]
T - 75	0.15	0.09	0.71	2.10
T - 60	0.39[b]	0.14	0.82	0.90
T - 45	0.15	0.23	1.10	2.55[b]
T - 30	0.20	0.26	1.06	1.75
T - 15	0.39[b]	0.16	1.02	1.25
T	0.12	0.20	1.55[b]	2.10[b]
T + 15	1.49[a]	2.79[a, **a**]	1.98[a]	3.20[a, **a**]
T + 30	0.90[a]	2.36[a, **a**]	3.81[a]	8.55[a, **a**]
T + 45	1.00[a]	1.75[a, **a**]	3.20[a]	13.35[a, **a**]
T + 60	0.59[a]	1.54[a, **a**]	2.22[a]	6.20[a, **a**]
T + 75	1.05[a]	0.60[a]	1.62[b]	8.98[a, **a**]
T + 90	0.59[a]	0.72[a]	1.54[a]	4.15[a, **b**]
T + 105	0.51[a]	0.23	1.73[a]	4.55[a, **a**]
T + 120	0.32[a]	2.34[a, **a**]	2.27[a]	3.65[a, **b**]
T + 135	0.27[a]	1.74[a, **a**]	1.25[b]	3.19[a, **a**]
T + 150	0.20[b]	0.95[a, **a**]	1.89[a]	1.92[a]
T + 165	0.49[a]	1.56[a, a]	2.07[a]	2.10[a]
T + 180	0.10	0.42[a, **a**]	1.28	4.10[a, **a**]
T + 195	0.12	0.63[a, **a**]	1.78[a]	3.90[a, **a**]
T + 210	0.15[b]	0.52[a, **b**]	1.42[a]	2.45[a, **a**]
T + 225	0.15[b]	0.35[a, **b**]	1.28[a]	2.95[a, **a**]
T + 240	0.15[b]	0.61[a, **b**]	1.46[a]	4.25[a, **a**]
T + 255	0.10	0.48[a, **a**]	0.95	3.10[a, **a**]
T + 270	0.07	0.47[a, **a**]	0.87	1.80[a, **b**]
T + 285	0.10	0.41[a, **a**]	1.23	1.60
T + 300	0.29[a]	0.23	1.44[a]	3.60[a, **a**]
T + 315	0.15[b]	0.35[a]	1.20	2.55[a, **a**]
T + 330	0.10	0.41[a, **a**]	1.20	2.75[a, **a**]
T + 345	0.12[b]	0.12	1.12	1.85
T + 360	0.07	0.32[a, **a**]	1.01	2.20[a, **a**]
T + 375	0.10	0.34[a, **a**]	1.20[b]	3.20[a, **a**]
T + 390	0.00	0.42[a, **a**]	0.95	2.60[a, **a**]
T + 405	0.17[a]	0.51[a, **a**]	1.05	2.10[a, **a**]
T + 420	0.15[b]	0.10	1.31[a]	1.51
T + 435	0.15[b]	0.50[a, **b**]	1.04	1.09
T + 450	0.12[b]	0.50[a, **b**]	1.07[b]	2.10[a, **a**]
T + 465	0.07	0.35[a, **a**]	0.94	1.55
T + 480	0.05	0.32[a, **a**]	0.90	2.70[a, **a**]
T + 495	0.15[b]	0.31[a, **b**]	1.17	2.80[a, **a**]
T + 510	0.05	0.14	1.17[b]	2.30[a, **a**]
T + 525	0.07	0.25	1.24[b]	3.00[a, **a**]
T + 540	0.07	0.35[a, **a**]	0.99	1.90[a, **a**]
T + 555	0.10	0.12	1.08[b]	2.10[a, a]
T + 570	0.05	0.84[a, **a**]	0.62	1.90[a, **a**]
T + 585	0.05	0.64[a, **a**]	1.10	0.65
T + 600	0.05	0.31[a, **a**]	0.66	2.25[a, **a**]

Table 3.3: Mean Absolute Price Changes Around Repo Rate Announcement.

a/b = the difference between the announcement and the non-announcement is significant at the 1%/5% level.
a/b = the difference between the not-expected announcement and the expected announcement is significant at the 1%/5% level.
E/NE represents expected/not-expected announcements.

Table 3.4 presents the mean number of transactions (trade frequency) around the announcement time. Our results indicate that the mean number of transactions prior to the announcement release are insignificantly different from the non-announcement period for the FTSE100, but are generally significantly greater for the Short Sterling. Following the announcement both contracts begin reacting to the news within 15 seconds. The mean number of transactions are initially large. During the first 30 seconds both contracts exhibit a mean number of transactions following a not-expected announcement of around twice as large as the respective expected announcement period. This relationship persists for the remainder of the twelve-minute window. The mean number of transactions for both contracts following a not-expected announcement remains significantly greater than both the non-announcement period and the respective expected announcement period for much of the remainder of the twelve-minute window. However there is evidence for both contracts of an increased mean number of trades following an expected announcement, these remain significantly greater than the non-announcement period for much of the remainder of the twelve-minute window.

Next we consider the mean trade size around the announcement time as shown in Table 3.5. Our results indicate that for both contracts, intervals prior to the release time have smaller trade sizes, with the smallest trades occurring prior to the release of a not-expected announcement. This suggests that market participants are unwilling to trade prior to an announcement and are even more reluctant to trade prior to a not-expected announcement. Following an announcement, both contracts reveal significantly larger trade sizes within the first 15 seconds. For the Short Sterling following a not-expected announcement the average trade size remains higher than both the non-announcement period and the respective expected announcement for much of the remainder of the twelve-minute window. However there is evidence of increased mean trade sizes following an expected announcement, these remain significant for much of the remainder of the twelve-minute window. For the FTSE 100 following a not-expected announcement the average trade size remains significantly greater than the non-announcement period for much of the remainder of the twelve-minute window, although only significantly greater than the respective expected announcement period for the first 75 seconds, although there are significant later intermittent intervals. Following an expected announcement trade size remains greater than the non-announcement period for much of the 10 minutes, although these are rarely significant.

	Short Sterling				FTSE100			
	Pre-ET		Post-ET		Pre-ET		Post-ET	
Non-Announcement	0.10		0.30		0.86		2.85	
Time Interval	E	NE	E	NE	E	NE	E	NE
T - 105	0.75^{a}	0.50^{a}	1.09^{b}	0.75^{a}	0.67	1.80	2.03	1.00^{b}
T - 90	0.25	0.50^{a,b}	0.79^{b}	0.75^{a}	1.33	1.80	1.83	3.40
T - 75	0.25	0.33	0.45	0.50	1.17	1.00	3.09^{b}	3.60
T - 60	0.38^{b}	0.50^{a}	0.58	0.75^{a,a}	0.50	0.80	2.06	1.20
T - 45	0.75^{a}	0.67^{a}	0.79^{b}	0.75^{a}	0.33	1.40	2.09	3.00
T - 30	0.38^{b}	0.33	1.06	0.25	0.83	1.20	2.49	1.20
T - 15	0.88^{a}	0.33^{a}	0.58	0.50	1.00	0.60	2.29	3.60
T	0.38^{b}	1.00^{a,a}	0.48	0.25	1.00	1.00	2.60	2.00
T + 15	0.50^{a}	0.67^{a,b}	3.30^{a}	5.75^{a,a}	1.50	1.70^{a}	4.57^{a}	6.60^{a}
T + 30	0.50^{a}	0.68^{a,b}	4.20^{a}	8.75^{a,a}	1.83^{b}	1.89^{a}	7.80^{a}	27.40^{a,a}
T + 45	0.50^{a}	0.73^{a,b}	3.97^{a}	5.25^{a,a}	2.50^{b}	2.80^{b}	7.80^{a}	36.40^{aa}
T + 60	0.50^{a}	0.55^{a}	4.06^{a}	5.75^{a,a}	2.33^{b}	2.60^{b,b}	6.91^{a}	24.40^{aa}
T + 75	0.56^{a}	0.67^{a}	3.61^{a}	9.00^{a,a}	2.17^{b}	2.80^{a,a}	6.09^{a}	17.80^{aa}
T + 90	0.58^{a}	0.67^{a}	3.18^{a}	3.25^{a}	1.17	2.40^{a,a}	6.23^{a}	16.00^{bb}
T + 105	0.63^{a}	0.67^{a}	3.18^{a}	4.25^{a,b}	0.67	2.40^{a,a}	2.03	14.60^{bb}
T + 120	0.67^{a}	0.92^{a,b}	2.58^{a}	3.75^{a,a}	2.50^{b}	3.20^{a,a}	5.63^{a}	12.80^{bb}
T + 135	0.38^{b}	1.00^{a,a}	3.06^{a}	4.25^{a,a}	1.33	3.20^{a,a}	3.94^{b}	11.00^{bb}
T + 150	0.63^{a}	0.83^{a}	1.21^{a}	4.00^{a,a}	2.33^{b}	2.86^{a}	6.40^{a}	6.40
T + 165	0.63^{a}	1.33^{a,a}	1.67^{a}	3.50^{a,a}	1.67	2.60^{a,a}	4.34^{b}	12.40^{ab}
T + 180	0.38^{b}	0.50^{a}	1.27^{a}	2.25^{a,b}	2.17^{b}	2.20^{b}	4.54^{b}	7.80
T + 195	0.05	0.67^{a,a}	1.09^{b}	2.50^{a,a}	3.00^{b}	3.00^{b}	4.26^{a}	8.60
T + 210	0.75^{a}	1.00^{a}	1.03	3.25^{a,a}	1.37	1.40	4.06^{a}	5.80^{b}
T + 225	0.63^{a}	0.92^{a}	0.58	2.75^{a,a}	1.50	3.00^{a,b}	4.14^{a}	9.60
T + 240	0.13	0.83^{a,a}	1.21^{b}	2.25^{a,b}	1.00	2.60^{a,b}	5.63^{a}	5.80^{a}
T + 255	0.63^{a}	0.73^{a}	0.58	1.00^{b}	1.50	2.20	4.14^{a}	11.00^{b}
T + 270	0.38^{b}	0.50^{a}	0.45	3.50^{a,a}	1.83^{b}	1.80	3.34	11.40^{aa}
T + 285	0.75^{a}	0.79^{a}	0.85	2.50^{a,a}	2.67^{b}	2.60	4.66^{a}	14.40^{aa}
T + 300	0.75^{a}	0.83^{a}	1.18^{b}	1.87^{a}	2.50^{b}	2.55	6.11^{a}	8.40
T + 315	0.50^{a}	0.58^{a}	0.91^{b}	1.25^{a}	1.33	1.60^{b}	5.43^{a}	6.80^{b}
T + 330	0.38^{b}	0.50^{a}	1.42^{a}	2.00^{a}	1.00	1.60	3.83^{a}	7.40
T + 345	0.38^{b}	0.50^{a}	1.00^{a}	1.25^{a}	2.17^{b}	2.60	3.71^{b}	6.00
T + 360	0.25	0.67^{a,b}	0.73	4.50^{a,a}	1.33	2.60^{b}	3.83^{a}	7.00^{a,b}
T + 375	0.50^{a}	0.50^{a}	0.91^{b}	1.50^{a}	1.50	2.00^{a}	2.97	8.20^{a,b}
T + 390	0.13	0.67^{a,a}	0.61	2.00^{a,a}	1.67	2.60	3.74^{a}	10.00^{aa}
T + 405	0.50^{a}	0.67^{a}	0.70	1.00^{b}	2.00^{b}	2.00	3.91^{a}	9.00^{aa}
T + 420	0.50^{a}	0.56^{b}	0.76	1.06	2.17^{b}	2.40	4.03^{b}	8.00^{b}
T + 435	0.50^{a}	0.50^{a}	0.79	1.75^{a,a}	1.00	1.40	3.86^{b}	2.20
T + 450	0.50^{a}	0.52^{a}	0.88	2.00^{a,a}	1.50	1.52	2.91^{b}	4.60
T + 465	0.38^{b}	0.50^{a}	0.94^{b}	2.50^{a,a}	1.00	1.40^{b}	3.40^{a}	5.20
T + 480	0.25	0.50^{a,a}	0.64	2.75^{a,a}	1.33	2.00	2.97	5.80
T + 495	0.13	0.50^{a,a}	0.73	2.25^{a,a}	1.33	2.20	3.03	6.40^{b}
T + 510	0.25	0.48	0.36	0.75	1.67^{b}	2.19	3.57^{b}	5.60
T + 525	0.13	0.83^{a,a}	0.48	1.25^{a,b}	2.17^{b}	2.39^{a}	4.11^{a}	5.00
T + 540	0.13	0.16	0.88	1.00^{b}	1.67^{b}	2.06	3.09^{b}	4.20
T + 555	0.25	0.36	0.91^{b}	1.25^{a}	1.50	2.20^{b}	3.20	7.00^{a,b}
T + 570	0.13	0.67^{a,a}	0.45	5.25^{a,a}	1.67	2.00	3.26^{b}	7.40^{a,b}
T + 585	0.13	0.33^{b,b}	0.36	1.75^{a,a}	1.33	2.80^{b}	3.11^{b}	7.80^{a,b}
T + 600	0.13	0.83^{a,a}	0.55	3.25^{a,a}	1.17	2.60^{b}	2.34	3.00

Table 3.4: Trade Frequency Around Repo Rate Announcement

a/b = the difference between the announcement and the non-announcement is significant at the 1%/5% level.
a/b = the difference between the not-expected announcement and the expected announcement is significant at the 1%/5% level.
E/NE represents expected/not-expected announcements.
Pre-ET/Post-ET represents the pre/post electronic trading periods

	Short Sterling				FTSE100			
	Pre-ET		Post-ET		Pre-ET		Post-ET	
Non-Announcement	65.51		78.42		12.44		3.71	
Time Interval	E	NE	E	NE	E	NE	E	NE
T - 105	61.32	69.51	71.65^{b}	75.45	9.46^{b}	10.23	3.50	3.42
T - 90	68.45	59.23^{b}	72.23	71.23	10.23	9.65	2.99^{b}	2.50^{a}
T - 75	59.36^{b}	61.62	69.52^{a}	73.59	8.33^{a}	7.45^{a}	3.58	3.69
T - 60	62.63	53.59^{a,b}	76.54	75.23	9.10^{b}	6.89^{a}	3.23	3.21
T - 45	63.65	65.15	68.92^{a}	62.21^{a}	11.23	8.45^{b}	2.86^{b}	2.49^{a}
T - 30	54.36^{a}	56.43^{b}	72.58	74.31	10.52	8.96	2.45^{a}	2.23^{a}
T - 15	59.84	60.49	73.65	69.63^{b}	8.67^{a}	7.10^{a}	3.61	2.86^{b,b}
T	63.52	62.13	76.62	63.48^{a,b}	9.63	8.56^{a,b}	3.51	2.41^{a,a}
T + 15	75.31^{a}	83.62^{a}	82.31	95.63^{a,b}	13.45^{b}	14.56^{a,b}	4.02	4.82^{a,b}
T + 30	82.31^{a}	88.95^{a}	88.96^{a}	96.58^{a}	14.56^{a}	15.63^{a}	4.33^{b}	4.99^{a,b}
T + 45	68.62	78.62^{a,a}	80.13	89.30^{a,a}	13.15	16.15^{a,a}	3.95	5.27^{a,a}
T + 60	63.23	69.41	89.56^{a}	91.28^{a}	11.23	15.98^{a,a}	4.56^{a}	4.75^{a}
T + 75	71.45^{b}	82.49^{a}	92.32^{a}	95.43^{a}	12.56	14.32^{a,a}	3.81	4.52^{a,a}
T + 90	84.35^{a}	88.69^{a}	95.13^{a}	96.45^{a}	14.53^{a}	12.56	4.59^{a}	5.05^{a}
T + 105	69.21	75.65^{a,b}	82.45	98.37^{a,b}	12.56	12.83	3.79	4.28^{b,b}
T + 120	63.34	79.58^{a,a}	86.15^{b}	91.25^{a}	13.29^{b}	13.03	4.10	4.65^{a,b}
T + 135	68.23	81.45^{a,a}	79.47	90.08^{a,a}	11.52	13.52^{a,a}	4.63^{a}	4.73^{a}
T + 150	86.52^{a}	92.45^{a}	82.15	86.45	13.58^{a}	12.84	4.25^{b}	5.02^{a,b}
T + 165	73.45^{b}	81.25^{a,b}	80.48	88.69^{b}	14.52^{a}	13.60^{a}	4.60^{a}	4.80^{a}
T + 180	71.25	78.84^{a,b}	92.56^{a}	92.26^{a}	10.25	12.01	3.92	4.38^{b}
T + 195	69.69	79.58^{a,a}	88.56^{a}	88.62^{a}	12.89	12.63	3.76	4.21
T + 210	75.45^{b}	73.65^{b}	85.95^{b}	84.60	13.80^{a}	14.25^{a}	4.28^{b}	4.76^{a}
T + 225	71.65	82.14^{a,b}	78.52	82.52	12.08	13.67^{a,a}	3.85	4.59^{a,b}
T + 240	77.59^{b}	83.59^{a}	81.32	86.45^{b}	13.69^{b}	13.08	4.65^{a}	4.95^{a}
T + 255	75.36	78.45^{a}	92.56^{a}	89.14^{a}	11.25	12.92	3.82	4.28
T + 270	82.36^{a}	80.23^{a}	75.63	90.32^{a,a}	13.59^{b}	13.80^{a}	4.25^{b}	4.50^{a}
T + 285	85.36^{a}	83.59^{a}	89.92^{a}	96.53^{a}	14.02^{a}	14.62^{a}	4.09	4.49^{a,b}
T + 300	92.32^{a}	89.93^{a}	98.32^{a}	87.13	13.85^{a}	14.03^{a}	4.12	4.73^{a,a}
T + 315	79.89^{a}	82.45^{a}	79.65	85.09^{b,b}	13.20	13.50^{b}	4.50^{a}	5.11^{a,b}
T + 330	65.32	78.53^{a,a}	83.46	88.54^{a}	12.58	13.08	3.99	4.54^{a,b}
T + 345	75.32^{b}	86.39^{a,b}	86.15^{b}	89.04^{a}	13.60^{b}	13.49^{b}	4.29^{b}	4.68^{a,b}
T + 360	69.37	70.45	81.23	80.23	13.50	13.83^{a}	4.59^{a}	4.88^{a}
T + 375	72.45	82.13^{a,a}	89.75^{a}	91.25^{a}	12.89	12.96	3.75	4.29
T + 390	78.14^{b}	88.83^{a,b}	85.62	85.69	12.71	12.84	3.62	4.31
T + 405	76.32^{b}	90.35^{a,a}	87.46^{b}	93.68^{a}	12.65	13.57^{a,a}	3.88	4.45^{b}
T + 420	81.49^{a}	78.35^{a}	92.10^{a}	96.08^{a}	13.09	13.54^{b}	4.15	4.60^{a}
T + 435	83.65^{a}	85.13^{a}	84.15	83.05	11.98	12.63	3.78	4.32
T + 450	78.50^{b}	83.26^{a}	85.45	88.78^{a}	12.36	12.38	3.75	4.09
T + 465	85.23^{a}	86.15^{a}	81.98	91.59^{a,b}	12.68	12.93	3.86	4.27
T + 480	72.24	85.00^{a,b}	84.65	90.35^{a,b}	13.59^{b}	13.48^{b}	4.27^{b}	4.39^{b}
T + 495	76.95^{b}	80.31^{a}	89.18^{b}	94.25^{a}	12.45	13.60^{a,a}	3.76	4.18
T + 510	88.82^{a}	95.50^{a}	86.31^{b}	98.32^{a}	13.59	13.92^{a}	4.11	4.48^{a}
T + 525	84.32^{a}	84.99^{a}	84.13	90.29^{a,b}	13.80^{a}	13.49	4.25	4.55^{a}
T + 540	68.52	78.23^{a,b}	92.03^{a}	95.56^{a}	13.59	12.83	4.95^{a}	4.89^{a}
T + 555	78.19^{a}	89.12^{a,b}	80.45	85.40^{b}	12.80	13.62^{b}	3.94	4.39^{b}
T + 570	76.63	80.45^{a,a}	79.52	80.56	13.69^{a}	14.02^{a}	4.12	4.85^{a}
T + 585	78.52^{a}	82.31^{a}	86.58^{b}	92.30^{a}	13.58	13.95^{a}	4.05	4.36
T + 600	70.51	76.23^{a,b}	80.23	89.59^{a,b}	12.93	13.29	4.19	4.78^{a}

Table 3.5: Trade Size Around Repo Rate Announcement

a/b = the difference between the announcement and the non-announcement is significant at the 1%/5% level.
a/b = the difference between the not-expected announcement and the expected announcement is significant at the 1%/5% level.
E/NE represents expected/not-expected announcements
Pre-ET/Post-ET represents the pre/post electronic trading periods.

3.4.1.2 The Duration of the Adjustment Process

To examine the duration of the adjustment process we calculate the average percentage of continuations across both transactions and 15-second time intervals. A continuation is defined as a price change in the same direction as the previous price change, while a price change in the opposite direction to the previous price change is termed a reversal.

For example in the series of prices shown in Figure 3.3, the first observed price change is from P_1 to P_2, which is a price decrease. The second observed price change is from P_2 to P_3, which is a price increase. Since the second price change is in the opposite direction to the first price change, the second price change is classified as a reversal. The third price change from P_3 to P_4, is a price increase, and is classified as a continuation since this is in the same direction as the second price change. Similarly P_5 to P_6 is a continuation, since its price change is in the same direction as the previous price change.

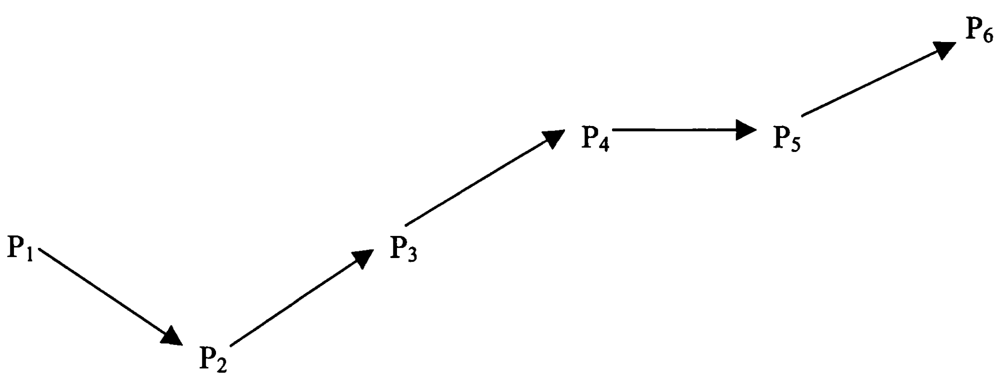

Figure 3.3: An Example of a Series of Price Changes.

The arrival of information in the market generally causes an imbalance in the supply and demand for a security at the existing price level. An adjustment then occurs, and a higher level of continuations should be observed as the price adjusts to a new equilibrium.

We compare the pattern of continuations after both not-expected and expected announcements with the pattern for non-announcement days. The duration of the adjustment process is indicated by the time taken for continuations to return to 'normal' levels. First percentage continuations are calculated for each 15-second interval of the announcement window for both expected and not-expected announcement days. We test these continuations for statistically significant differences from the 'normal' levels of continuations, which are defined as the average percentage of continuations during the twelve-minute window across the non-announcement days, and for statistically significant differences between the level of continuations following not expected and expected announcements. Then we repeat the analysis across the first thirty transactions after the announcement.

Table 3.6 presents the mean percentage of continuations around a repo rate announcement over clock-time and Table 3.7 presents the mean percentage of continuations following a repo rate announcement over transaction time. Our results indicate that price continuations are rare in the period prior to the announcement. For the Short Sterling continuations become significantly elevated within 15 seconds of the announcement time. We found the highest percentage of continuations followed a not-expected announcement and that these remained significant for 60 seconds, with additional significant intervals appearing in the third minute following an announcement. Although we found an elevated level of continuations following an expected announcement, these remained significant for only 45 seconds. In terms of transaction time it takes only 8 transactions before continuations return to normal levels following an expected announcement in comparison to at least 30 transactions following an unexpected announcement. For the FTSE 100, the results indicate that for the first 15 seconds following a not-expected announcement the level of continuations are significantly lower than the non-announcement period, this indicates that the high degree of surprise corresponding to these unexpected announcements meant that market participants took time to digest the announcements' implications upon the futures price before reacting to the new information. However for much of the remainder of the twelve-minute window continuations remain significantly greater than both the non-announcement period and the respective expected announcement period. In terms of transaction time, following a not-expected announcement the level of continuations became significantly elevated after 3 transactions and remained significant for much of the thirty transactions. However following an expected announcement, although the level of continuations remained greater than the non-announcement period, these were rarely significant over transactions. Again, we confirm our earlier finding that following an expected/not-expected announcement our results are indicative of a shorter/longer price adjustment period than that found in Ap Gwilym et al. (1998).

	Short Sterling		FTSE100	
Non-Announcement	0.00		5.38	
Time Interval	E	NE	E	NE
T - 105	0.61	0.00	6.35	7.50
T – 90	0.61	0.00	2.14[b]	12.22
T – 75	0.00	0.00	7.26	14.29
T – 60	0.00	0.00	5.45	0.00[a]
T – 45	0.00	0.00	7.28	14.76
T – 30	0.00	0.00	5.99	11.00
T – 15	1.22	0.00	9.54	2.00[b]
T	0.00	0.00	7.16	0.00[a]
T + 15	12.19[a]	10.83[a]	14.47[a]	5.17[b]
T + 30	3.57[b]	12.00[a, a]	19.33[a]	29.41[b]
T + 45	5.63[b]	8.22[a, b]	15.78[a]	37.22[a, a]
T + 60	2.48	4.00[a, a]	17.69[a]	30.13[a]
T + 75	5.18[b]	0.71	11.75[a]	23.02[a, b]
T + 90	0.75	0.00	12.41[a]	17.27[a]
T + 105	2.54	0.00	12.20[a]	24.49[b, b]
T + 120	0.00	5.83[a, a]	15.01[a]	26.83[a]
T + 135	0.00	3.01[a, a]	15.48[a]	26.54[a]
T + 150	0.00	1.67	14.12[a]	17.80
T + 165	0.00	2.50[b]	14.70[a]	19.82
T + 180	0.00	0.00	12.20[b]	23.49[a, b]
T + 195	0.00	0.00	18.32[a]	29.33[a]
T + 210	0.00	0.00	12.52[a]	11.22
T + 225	0.81	0.00	9.92	19.50[a, b]
T + 240	0.00	0.00	17.25[a]	17.44
T + 255	0.00	0.00	11.97[a]	25.75[b, b]
T + 270	0.00	0.00	10.41[b]	16.61
T + 285	0.00	3.33[a, a]	9.34	14.22
T + 300	0.00	0.00	20.73[a]	6.04
T + 315	0.00	0.00	12.28[b]	10.33
T + 330	0.00	0.00	9.71[b]	22.04[b]
T + 345	0.00	0.00	9.80[b]	15.78
T + 360	0.00	0.00	5.95	24.43[b, b]
T + 375	0.00	0.00	12.07[b]	24.66[b]
T + 390	0.00	5.00[b]	10.27	9.27
T+ 405	0.00	0.00	10.84[b]	17.26[b]
T + 420	0.00	0.00	9.76	6.00
T + 435	0.00	0.00	10.75[b]	5.00
T + 450	0.00	0.00	13.72[a]	12.50
T + 465	0.00	0.00	7.03	7.26
T + 480	0.00	0.00	8.71	14.88
T + 495	0.00	0.00	5.59	16.89[b]
T + 510	0.00	0.00	10.76	13.91
T + 525	0.00	0.00	14.50[a]	23.61[b]
T + 540	0.00	0.00	8.26	10.00
T + 555	0.00	0.00	11.28	8.22
T + 570	0.00	0.56	7.88	18.93[a, b]
T + 585	0.00	0.00	9.79	11.91
T + 600	0.00	0.00	3.48	10.83

Table 3.6: Mean Percentage Continuations Around Repo Rate Announcement

a/b = the difference between the announcement and the non-announcement is significant at the 1%/5% level.
a/b = the difference between the not-expected announcement and the expected announcement is significant at the 1%/5% level.
E/NE represents expected/not-expected announcements

	Short Sterling		FTSE100	
Non-Announcement	4.84		24.09	
Transaction Number	**E**	**NE**	**E**	**NE**
1	46.341[a]	40.00[a]	34.15	30.00
2	31.71[a]	40.00[a,b]	41.46[b]	30.00
3	34.15[a]	70.00[a,b]	31.71	70.00[a,**a**]
4	26.83[a]	30.00[a]	29.27	30.00
5	26.83[a]	60.00[a,b]	31.71	50.00[a,**a**]
6	31.71[a]	30.00[a]	43.90[b]	30.00
7	26.83[a]	40.00[a,b]	48.78[a]	70.00[a,b]
8	21.95[a]	0.00[**a**]	19.51	80.00[a,**a**]
9	7.31	40.00[a,b]	14.63	40.00[a,**a**]
10	8.04	30.00[a,b]	34.15	50.00[a,**a**]
11	7.32	0.00	21.95	30.00
12	12.20	30.00[a,**a**]	29.27	10.00
13	4.88	30.00[a,**a**]	39.02	50.00[a,]
14	4.88	10.00	29.27	40.00[a,]
15	4.88	20.00[a,b]	26.83	50.00[a,**a**]
16	7.32	10.00	39.02	40.00
17	7.32	20.00[a,b]	17.07	40.00[a,**a**]
18	12.20	20.00[a,b]	24.39	40.00[a,**a**]
19	2.44	0.00	41.46[b]	40.00[a]
20	2.44	20.00[a,**a**]	43.90[b]	20.00
21	7.32	30.00[a,**a**]	29.27	30.00
22	14.63	10.00	39.02	50.00[a,]
23	4.88	20.00[a,**a**]	26.83	60.00[b]
24	4.88	10.00	46.34[a]	20.00
25	12.20	30.00[a,b]	29.27	30.00
26	4.88	40.00[a,**a**]	31.71	20.00
27	2.44	20.00[a,**a**]	36.59	50.00[a,]
28	2.44	0.00	34.15	40.00
29	7.32	30.00[a,b]	21.95	50.00[a,**a**]
30	2.44	20.00[a,**a**]	31.71	30.00

Table 3.7: Mean Percentage Continuations Across Transactions Following a Repo Rate Announcement

a/b = the difference between the announcement and the non-announcement is significant at the 1%/5% level.
a/b = the difference between the not-expected announcement and the expected announcement is significant at the 1%/5% level.
E/NE represents expected/not-expected announcements.

3.4.1.3 The Speed of the Adjustment Process

To determine how much of the adjustment from the old equilibrium price to the new equilibrium price occurs during each interval, we calculate cumulative average adjusted returns as proposed by Ederington and Lee (1995) and followed by others. Since there is no independent measure of whether an announcement is bullish or bearish we interpret this from the sign of the return over the first thirty seconds following a repo rate announcement.

The adjusted return for each interval is calculated as;

$$AR_t = R_t * D_t \tag{3.1}$$

where D_t is determined as follows. Let $R_{(0,30)}$ represent the return over the first thirty-second interval following an announcement at time T. For intervals before T or after $T + 30$ seconds, $D_t = 1$ if $R_{(0,30)} > 0$; $D_t = -1$ if $R_{(0,30)} < 0$; and $D_t = 0$ if $R_{(0,30)} = 0$. This forces returns that are in the same direction as the initial price change to be positive, and returns that are in the opposite direction to be negative. To avoid spurious correlation between R_t and D_t, for the two intervals within the period from T to $T + 30$ seconds, we define $D_t = 1$ if $(R_{(0,30)} - R_t) > 0$, $D_t = -1$ if $(R_{(0,30)} - R_t) < 0$ and $D_t = 0$ if $(R_{(0,30)} - R_t) = 0$. The average adjusted returns are calculated for each 15-second interval, and the null hypothesis that $AAR_t = 0$ is tested for each interval. If there is no information leakage prior to any announcement then AAR_t should be insignificantly different from zero for intervals prior to the release. Intervals after the announcement should be significantly greater than zero during the adjustment period and insignificantly different from zero once the adjustment is complete.

The AAR_t are summed from interval 1 ($T - 120$ seconds to $T - 105$ seconds) to interval t to form the cumulative average adjusted returns, CAR_t. The ratio of CAR_t to the CAR at the end of the twelve-minute announcement window determines how much of the overall adjustment occurs by time t.

Table 3.8 presents the average adjusted returns, cumulative adjusted returns and the ratio of CAR_t to the CAR at the end of the twelve-minute window. Figures 3.4 and 3.5 show plots of the ratio values of the Short Sterling and the FTSE 100 for the twelve-minute window respectively. Our results indicate that prior to an announcement the AAR_t are small and insignificant for the Short Sterling, however for the FTSE100, the AAR_t are relatively large prior to an announcement although generally insignificant. Following an announcement both contracts begin reacting within 15 seconds, reporting large significant AAR_t. Both contracts show larger AAR_t following a not-expected announcement compared with those found following an expected announcement.

For the Short Sterling following a not-expected announcement returns are significantly greater than zero for the first 30 seconds, then over the next 15 seconds a significant negative AAR_t occurs indicating the start of some correction from an initial over-reaction to the announcement. The following three intervals show negative AAR_t, with a significant negative AAR_t occurring at T+120, then at T+135 a significant positive AAR_t is found indicating a second correction. Later AAR_t are generally insignificant with one exception, this being a significant negative AAR_t found at T+210. Following an expected announcement returns are generally significantly less than zero for the first 75 seconds, with a significant positive AAR_t occurring at T+90, indicating a small price re-adjustment. Later AAR_t remain small and insignificant.

For the FTSE100 following a not-expected announcement, returns are significantly greater than zero for the first 15 seconds. Although these returns remain insignificant for much of the remainder of the first minute, during the second minute these returns are generally significantly greater than zero. This indicates a delayed reaction while market participants attempted to assess the announcements implications upon the futures price before entering the market. Later AAR_t were frequently found to be significantly different from zero. Following an expected announcement returns are significantly greater than zero for the first 15 seconds, in the following intervals AAR_t are generally significantly negative for the first 225 seconds after the announcement, although a significant positive AAR_t occurs at T+135. For the remainder of the twelve-minute window AAR_t are generally insignificant with one exception, a negative AAR_t occurs at T+315.

The ratio of CAR_t to T+600 value for the Short Sterling following a not-expected announcement indicates that the ratio rises to over 2 after only 30 seconds and then gradually decreases for a further 75 seconds with evidence of a large under-reaction occurring at T+120, which is then corrected in the following 30 seconds. There is evidence of a further under-reaction for around two minutes occurring after T+275, which eventually begins to stablilise at around T+330. Following an expected announcement the ratio gradually rises to around 1.2 after 75 seconds and remains relatively stable for the remainder of the twelve-minute window.

For the FTSE 100 the ratio following a not-expected announcement takes 105 seconds to approach 1 and then remains above 1 for a further 195 seconds. Following this the ratio oscillates around 1 for the remainder of the twelve-minute window, with some exceptions where the ratio jumps to around 1.5 at around T+495. Following an expected announcement the ratio takes 120 seconds to approach 1. Following this the ratio oscillates around 1 for a further 180 seconds and then remains above 1 before remaining stable at T+375.

Finally, we find that generally following an expected/not-expected announcement prices adjust more quickly/slowly than those found following an announcement in Ap Gwilym et al. (1998).

Time Interval	Short Sterling						FTSE100					
	E			NE			E			NE		
	AAR	CAR	Ratio	AAR	CAR	Ratio	AAR	CAR	Ratio	AAR	CAR	Ratio
T - 105	-0.05	-0.05	0.06	0.00	0.00	0.00	0.33	0.33	-0.13	0.00	0.00	0.00
T – 90	0.05	0.00	0.00	0.10	0.10	0.06	0.02	0.35	-0.14	1.20	1.20	0.15
T – 75	-0.05	-0.05	0.06	0.00	0.10	0.06	-0.04	0.32	-0.13	-0.90	0.30	0.04
T – 60	0.05	0.00	0.00	0.00	0.10	0.06	-0.41[b]	-0.10	0.04	-0.40	-0.10	-0.01
T – 45	-0.05	-0.05	0.06	0.20	0.30	0.19	-0.23	-0.33	0.13	0.85	0.75	0.09
T – 30	-0.02	-0.07	0.10	-0.10	0.20	0.13	-0.09	-0.41	0.17	0.75	1.50	0.18
T – 15	0.07	0.00	0.00	0.00	0.20	0.13	0.02	-0.39	0.16	0.35	1.85	0.23
T	0.00	0.00	0.00	-0.10	0.10	0.06	-1.21[a]	-1.60	0.65	0.60	2.45	0.30
T + 15	-0.22[a]	-0.22	0.29	2.60[a]	2.70	1.69	0.66[a]	-0.94	0.38	1.50[a]	3.95	0.48
T + 30	-0.02	-0.24	0.32	0.80[a]	3.50	2.19	0.22	-0.73	0.30	0.45	4.40	0.54
T + 45	-0.37[a]	-0.61	0.81	-0.70[b]	2.80	1.75	-0.62[a]	-1.35	0.55	-0.35	4.05	0.49
T + 60	-0.02	-0.63	0.84	-0.30	2.50	1.56	-0.22	-1.57	0.64	0.05	4.10	0.50
T + 75	-0.34[a]	-0.98	1.29	-0.30	2.20	1.38	0.13	-1.44	0.59	3.50[a]	7.60	0.93
T + 90	0.29[a]	-0.68	0.90	-0.10	2.10	1.31	-0.44[b]	-1.88	0.77	-0.60	7.00	0.85
T + 105	-0.15	-0.83	1.10	0.00	2.10	1.31	-0.28	-2.16	0.88	1.90[a]	8.90	1.08
T + 120	0.15	-0.68	0.90	-1.50[a]	0.60	0.38	-0.18	-2.35	0.96	1.60[a]	10.50	1.28
T + 135	0.05	-0.63	0.84	1.20[a]	1.80	1.13	0.37[b]	-1.98	0.81	-1.94[a]	8.56	1.04
T + 150	-0.12	-0.76	1.00	-0.60	1.20	0.75	0.12	-1.85	0.76	0.95	9.51	1.16
T + 165	0.05	-0.71	0.94	0.40	1.60	1.00	-0.27	-2.12	0.87	-0.45	9.06	1.10
T + 180	-0.05	-0.76	1.00	-0.40	1.20	0.75	-0.48[b]	-2.60	1.06	-0.10	8.96	1.09
T + 195	-0.07	-0.83	1.10	0.00	1.20	0.75	0.82[a]	-1.78	0.73	2.10[a]	11.06	1.35
T + 210	-0.05	-0.88	1.16	-0.40[a]	0.80	0.50	-0.40[b]	-2.18	0.89	-1.55[a]	9.51	1.16
T + 225	-0.02	-0.90	1.19	0.10	0.90	0.56	-0.73[a]	-2.91	1.19	1.25[b]	10.76	1.31
T + 240	0.00	-0.90	1.19	0.10	1.00	0.63	-0.06	-2.97	1.21	-2.05[a]	8.71	1.06
T + 255	0.05	-0.85	1.13	0.00	1.00	0.63	-0.24	-3.22	1.31	1.60[a]	10.31	1.26

Table 3.8: Speed of Price Adjustment Around Repo Rate Announcement, (continued)
Average adjusted returns (AAR_t), cumulative average adjusted returns (CAR_t), and the ratio of CAR_t to the T+600 value. Significance of the AAR_t is based on the null that AAR_t=0, a=significant at the 1% interval, b=significant at the 5% interval. E/NE represents expected/not-expected announcements.

Time Interval	Short Sterling						FTSE100					
	Expected			Not-Expected			Expected			Not-Expected		
	AAR	CAR	Ratio	AAR	CAR	Ratio	AAR	CAR	Ratio	AAR	CAR	Ratio
T + 270	0.00	-0.85	1.13	0.20	1.20	0.75	0.18	-3.03	1.24	-0.10	10.21	1.24
T + 285	0.00	-0.85	1.13	0.10	1.30	0.81	0.15	-2.89	1.18	-0.50	9.71	1.18
T + 300	-0.07	-0.93	1.23	-0.10	1.20	0.75	-0.16	-3.05	1.24	-1.70[b]	8.01	0.98
T + 315	0.05	-0.88	1.16	0.10	1.30	0.81	-0.35[b]	-3.40	1.39	0.75	8.76	1.07
T + 330	0.02	-0.85	1.13	0.30	1.60	1.00	0.10	-3.30	1.35	-0.65	8.11	0.99
T + 345	0.05	-0.80	1.06	0.00	1.60	1.00	0.54	-2.77	1.13	-1.00	7.11	0.87
T + 360	-0.05	-0.85	1.13	0.00	1.60	1.00	-0.41	-3.18	1.30	1.80[a]	8.91	1.09
T + 375	-0.02	-0.88	1.16	-0.10	1.50	0.94	0.41	-2.77	1.13	0.10	9.01	1.10
T + 390	0.00	-0.88	1.16	0.10	1.60	1.00	0.06	-2.70	1.10	-0.50	8.51	1.04
T + 405	-0.02	-0.90	1.19	-0.20	1.40	0.88	0.01	-2.69	1.10	0.00	8.51	1.04
T + 420	0.00	-0.90	1.19	0.00	1.40	0.88	-0.02	-2.72	1.11	0.45	8.96	1.09
T + 435	0.05	-0.85	1.13	0.40	1.80	1.13	0.15	-2.56	1.05	-0.60	8.36	1.02
T + 450	-0.07	-0.93	1.23	-0.20	1.60	1.00	-0.01	-2.57	1.05	0.60	8.96	1.09
T + 465	0.07	-0.85	1.13	0.30	1.90	1.19	0.13	-2.44	1.00	-1.50[b]	7.46	0.91
T + 480	-0.02	-0.88	1.16	0.20	2.10	1.31	-0.30	-2.75	1.12	2.55[b]	10.01	1.22
T + 495	0.07	-0.80	1.06	0.00	2.10	1.31	0.41	-2.33	0.95	2.10[b]	12.11	1.48
T + 510	-0.02	-0.83	1.10	0.00	2.10	1.31	0.15	-2.18	0.89	-1.10	11.01	1.34
T + 525	0.05	-0.78	1.03	0.00	2.10	1.31	-0.27	-2.45	1.00	-2.00[a]	9.01	1.10
T + 540	0.00	-0.78	1.03	-0.30	1.80	1.13	-0.09	-2.54	1.04	-0.10	8.91	1.09
T + 555	0.02	-0.76	1.00	0.10	1.90	1.19	0.14	-2.40	0.98	-0.25	8.66	1.05
T + 570	0.00	-0.76	1.00	0.30	2.20	1.38	-0.09	-2.49	1.01	0.50	9.16	1.12
T + 585	0.00	-0.76	1.00	-0.40	1.80	1.13	0.07	-2.41	0.99	-0.05	9.11	1.11
T + 600	0.00	-0.76	1.00	-0.20	1.60	1.00	-0.04	-2.45	1.00	-0.90	8.21	1.00

Table 3.8: Speed of Price Adjustment Around Repo Rate Announcement

Average adjusted returns (AAR_t), cumulative average adjusted returns (CAR_t), and the ratio of CAR_t to the T+600 value. Significance of the AAR_t is based on the null that AAR_t=0, a=significant at the 1% interval, b=significant at the 5% interval. E/NE represents expected/not-expected announcements.

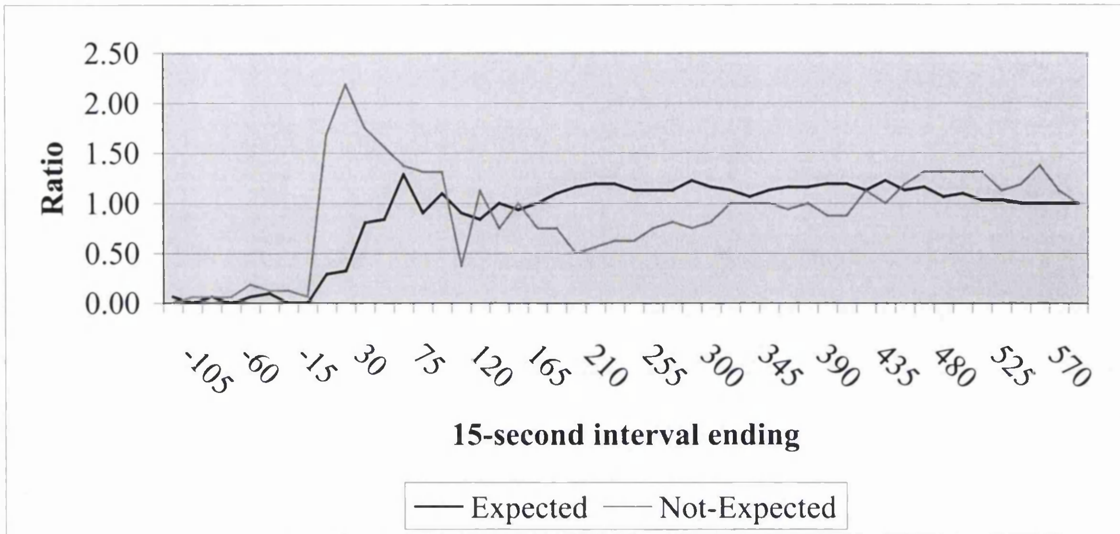

Figure 3.4: Speed of Price Adjustment for the Short Sterling

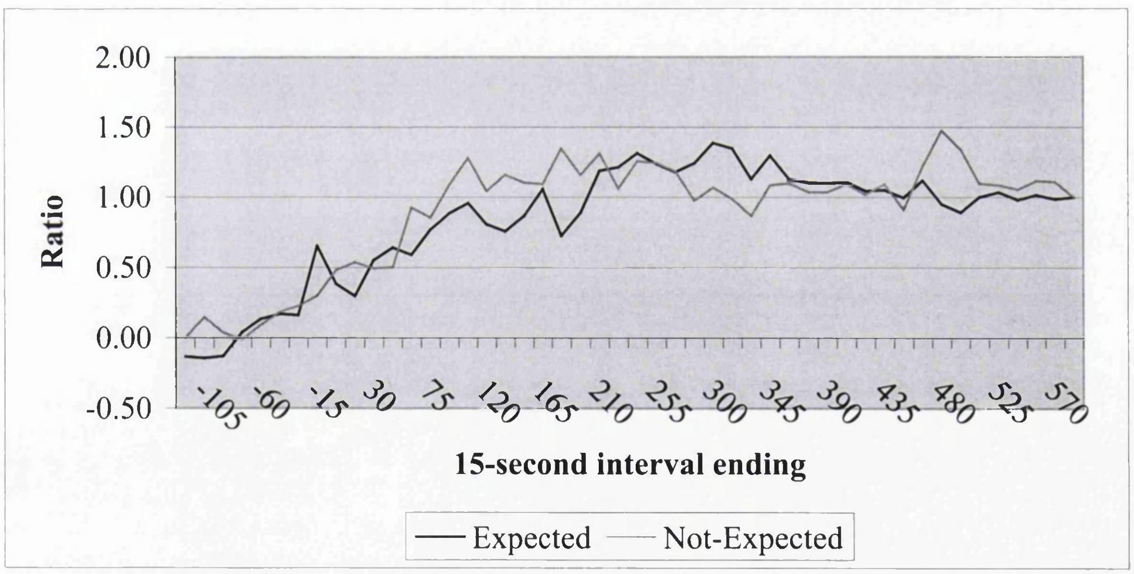

Figure 3.5: Speed of Price Adjustment for the FTSE100

Before presenting the second analysis of this chapter, we summarise our findings so far. We examined both the price and volume adjustment process following repo rate announcements for the Short Sterling and FTSE 100 futures contracts. We decomposed our announcement events into expected and not-expected announcements.

We found that price changes were significantly greater prior to an announcement and in particular for the FTSE100, where price changes prior to a not-expected announcement were significantly greater than both the respective expected announcement period and the non-announcement period. Following an announcement, both contracts show a larger price reaction following a not-expected announcement. Although these price changes remain significantly greater than both the respective expected announcement period and the non-announcement period for much of the first 30 transactions and the remainder of the twelve-minute window, they decline rapidly after 120 seconds for the Short Sterling, after an initial over-reaction and 75 seconds for the FTSE100. In contrast the reaction following an expected announcement reveals a faster adjustment process, and although these price changes remain significantly greater than the non-announcement period for much of the first 10 minutes they decline rapidly after 75 seconds for the Short Sterling and 60 seconds for the FTSE100, in transaction time they remain significant for around 14 transactions for the Short Sterling and around 7 transactions for the FTSE100.

Prior to an announcement, the Short Sterling exhibited an increased frequency of smaller trades. Following a not-expected announcement both trade frequency and trade size remained significantly greater than the respective expected announcement period and the non-announcement period for much of the remainder of the twelve-minute window. There is also evidence of an increased number of larger trades following an expected announcement.

For the FTSE 100, we found evidence of smaller trades prior to an announcement although no change in the mean number of trades. Following an announcement we found that the number of trades following a not-expected announcement remains significantly greater than both the respective expected announcement period and the non-announcement period. Trade size, following a not-expected announcement were significantly greater than the non-announcement period for much of the following 10 minutes. They remained only significantly greater than the expected announcement period for the first 75 seconds. Following an expected announcement, although trades sizes remained larger than the non-announcement period for much of the following 10 minutes, these were rarely significant.

We conclude that following an unexpected announcement both contracts react immediately to the new information and the adjustment process is characterised by large price changes, raised volatility and an increased number of larger trades. However we also found evidence of a market reaction albeit smaller, following an expected announcement. We explain that these findings are due to an element of uncertainty that still exists within all our expected announcements. This is because we determine an announcement as expected if more that 50 percent forecast the decision, therefore unless 100 percent forecast the decision there will always exist a certain element of surprise in the announcement, albeit a smaller surprise than that encountered by an unexpected announcement.

Finally, our results indicate a shorter/longer adjustment period following an expected/not-expected announcement than that found following an announcement in Ap Gwilym et al. (1998). We suggest that the majority of the price adjustment is explained by the degree of surprise associated with an announcement. Therefore in studies such as Ap Gwilym et al. (1998) where announcement data used contains both expected and unexpected components and not just the surprise element associated with an announcement, that the observed price adjustment is diluted by the expected components of that announcement.

The next section wishes to address this issue by providing an alternative analysis of the surprise element. This directly measures the unexpected component associated with each announcement.

3.4.2 The Effects of the Degree of Repo Rate Announcement Surprises upon Trading Volume

In the analyses above we have indicated that both trade frequency and trade size become elevated following a repo rate announcement, and that it is the degree of the unexpected component of each announcement that determines the amount of abnormal trade frequency and trade size observed following an announcement.

Following this observation, in our second analysis we utilise the repo rate survey data as shown in Table 3.1, to focus on simply the unexpected components of each announcement, which we separate into four surprise component states, $F50^{-}, F25^{-}, F25^{+}, F50^{+}$;

$F50^{-}$: The proportion of the market that forecast a decision 50 basis points below the actual decision.

$F25^{-}$: The proportion of the market that forecast a decision 25 basis points below the actual decision.

$F25^{+}$: The proportion of the market that forecast a decision 25 basis points above the actual decision.

$F50^{+}$: The proportion of the market that forecast a decision 50 basis points above the actual decision.

This permits the capture of all the unexpected components associated with each announcement, and provides measures of both the magnitude[3] and the direction[4] of the surprise element.

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[3] When we refer to the magnitude of the surprise element, we refer to both the proportion of the market that are surprised and the number of basis points the forecast is away from the decision.

[4] When we refer to the direction of the surprise element, we refer to whether the forecast is above or below the decision.

In our analysis we examine the impact of the degree of repo rate surprise upon trade volume, trade frequency and trade size. By examining the relationship between the state of surprise and trade volume, we illuminate the role of volume in the adjustment process to new information. For a further detailed analysis of the behaviour of trade volume, we examine the relationships between the state of surprise and both trade frequency and trade size. These analyses provide additional insights into the behaviour of market participants in response to new information.

3.4.2.1 Hypothesis

We predict that the greater the degree of surprise, to a repo rate announcement, the greater the market activity following the announcement (See Section 2.2.2).

3.4.2.2 The Model

The impact of a surprise component upon trade volume, trade frequency and trade size is examined by estimating the following linear regression equation:

$$MA_t = \alpha_0 + \beta_1 F50_t^- + \beta_2 F25_t^- + \beta_3 F25_t^+ + \beta_4 F50_t^+ + \delta D_t \ , \qquad (3.2)$$

Where MA_t = trading volume, trade frequency or natural log of trade size[5] from the time of the announcement to the first five minutes of trading after the announcement. The independent variable $F50_t^-$ is the mean proportion of market participants that forecast a decision of 50 basis points below the actual decision. The independent variable $F25_t^-$ is the mean proportion of market participants that forecast a decision of 25 basis points below the actual decision. The independent variable $F25_t^+$ is the mean proportion of market participants that forecast a decision of 25 basis points above the actual decision.

[5] When estimating Equation (3.2), with MA_t = trade size, we found for both the FTSE100 and the Short Sterling, the null hypothesis of normally distributed errors to be rejected (Jacque-Bera test statistics t=155.854, t=228.159 respectively). As a consequence of such extreme non-normality we took the natural log transformation of the dependent variable.

The independent variable $F50_t^+$ is the mean proportion of market participants that forecast a decision of 50 basis points above the actual decision. We include a dummy variable D_t where $D_t = 1$ if announcement occurred after electronic trading was introduced and zero elsewhere.

3.4.2.3 Empirical Results

3.4.2.3.1 Trade Volume

	Short Sterling			**FTSE100**		
	Coefficient	T-Statistic	Probability	Coefficient	T-Statistic	Probability
α_0	-1914.759	-1.372	0.177	-202.611	-1.017	0.315
β_1	-1041.739	-1.352	0.183	87.197	1.497	0.141
β_2	38.801	0.935	0.355	13.696	3.192*	0.003
β_3	70.460	2.661*	0.011	13.034	4.096*	0.000
β_4	28.295	0.578	0.566	7.741	0.849	0.400
δ	4764.804	5.258*	0.000	145.229	1.031	0.308

Table 3.9: The Effects of both Direction and Magnitude of Repo Rate Announcement Surprises upon Trading Volume.

Coefficient estimates, t-statistics and associated probabilities of Equation (3.2),

$$MA_t = \alpha_0 + \beta_1 F50_t^- + \beta_2 F25_t^- + \beta_3 F25_t^+ + \beta_4 F50_t^+ + \delta D_t + \varepsilon_i ,$$

The dependent variable, MA_t, is the trading volume for the first 5 minutes of post-announcement trading. The independent variables are; $F50_t^-$ is the mean proportion of market participants that forecast a decision of 50 basis points below the actual decision. $F25_t^-$ is the mean proportion of market participants that forecast a decision of 25 basis points below the actual decision. $F25_t^+$ is the mean proportion of market participants that forecast a decision of 25 basis points above the actual decision. $F50_t^+$ is the mean proportion of market participants that forecast a decision of 50 basis points above the actual decision. D_t, is a dummy variable representing the switch to electronic trading. *=significant at the1% level. Number of observations = 51.

Short Sterling: White Heteroskedasticity Test Statistics: 7.252 (probability=0.611).
LM Test for Serial Correlation Test Statistics: 0.141 (probability=0.932).
Jacque-Bera Test Statistics: 10.716 (probability=0.005).
Adjusted R^2 values=0.378.

FTSE100: White Heteroskedasticity Test Statistics: - (probability = -).
LM Test for Serial Correlation Test Statistics: 1.571 (probability=0.456).
Jacque-Bera Test Statistics: 4.779 (probability=0.092).
Adjusted R^2 values=0.442.

The results in Table 3.9 indicate that out of all the market participants who incorrectly forecast the repo rate decision, the forecast of a decision of 25 basis points above the decision is positively related to volume for both contracts, and a forecast of a decision of 25 basis points below the decision is positively related to volume for the FTSE100 only. In other words for the FTSE 100, any observed abnormal volume following a repo rate announcement is the consequence of a similar level of elevated trading by those who forecast a decision 25 basis points either side of the actual decision. However for the Short Sterling, any observed abnormal volume following an announcement appears to only be explained by those who forecast a decision 25 basis points above the actual announcement. In addition the switch to electronic trading appears to be positively related to trading volume for both contracts.

3.4.2.3.2 Trade Frequency

	Short Sterling			FTSE100		
	Coefficient	T-Statistic	Probability	Coefficient	T-Statistic	Probability
α_0	-27.019	-2.640*	0.011	-104.665	-2.447**	0.019
β_1	-14.547	-2.576*	0.013	18.089	1.140	0.261
β_2	0.829	2.725*	0.009	3.335	3.821*	0.000
β_3	0.889	4.576*	0.000	2.804	5.167*	0.000
β_4	-0.129	-0.359	0.722	1.242	1.330	0.190
δ	47.941	7.213*	0.000	123.411	3.337*	0.002
AR(1)	-	-	-	0.470	3.440*	0.001

Table 3.10: The Effects of both Direction and Magnitude of Repo Rate Announcement Surprises upon Trading Frequency.

Coefficient estimates, t-statistics and associated probabilities of Equation (3.2).

$$MA_t = \alpha_0 + \beta_1 F50_t^- + \beta_2 F25_t^- + \beta_3 F25_t^+ + \beta_4 F50_t^+ + \delta D_t + \lambda AR(1) + \varepsilon_i,$$

The dependent variable is the trading frequency for the first 5 minutes of post-announcement trading. The independent variables are; $F50_t^-$ is the mean proportion of market participants that forecast a decision of 50 basis points below the actual decision. $F25_t^-$ is the mean proportion of market participants that forecast a decision of 25 basis points below the actual decision. $F25_t^+$ is the mean proportion of market participants that forecast a decision of 25 basis points above the actual decision. $F50_t^+$ is the mean proportion of market participants that forecast a decision of 50 basis points above the actual decision. D_t, is a dummy variable representing the switch to electronic trading and AR(1) represents an autoregressive process of order one. *=significant at the1% level. **=significant at the 5% level. Number of observations = 51.

Short Sterling: White Heteroskedasticity Test Statistics: 7.904 (probability=0.544).
LM Test for Serial Correlation Test Statistics: 2.594 (probability=0.273).
Jacque-Bera Test Statistics: 0.594 (probability=0.743).
Adjusted R^2 values=0.537.

FTSE100: White Heteroskedasticity Test Statistics: 15.456 (probability = 0.079).
LM Test for Serial Correlation Test Statistics: 3.610 (probability=0.164).
Jacque-Bera Test Statistics: 0.380 (probability=0.827).
Adjusted R^2 values=0.585.

The results in Table 3.10 indicate that out of all the market participants who incorrectly forecast the repo rate decision, it appears for both contracts that those participants who forecast both 25 basis points below and 25 basis points above the repo rate decision are positively related to trade frequency. In addition, participants who forecast a repo rate of

50 basis points below the decision appear to be negatively related to the trade frequency of the Short Sterling only. In addition it appears that for the Short Sterling following an announcement those market participants that forecast a decision 25 basis points either side of the actual decision, trade equally more frequently. In contrast for the FTSE 100, although those who forecast a decision 25 basis points either side of the actual decision trade more frequently, those market participants that forecast a decision 25 basis points below the actual decision appear to explain more of the observed higher frequency of trading following an announcement. For both contracts the switch to electronic trading appears to be positively related to trade frequency (significant at the 1% level).

3.4.2.3.3 Trade Size

	Short Sterling			FTSE100		
	Coefficient	T-Statistic	Probability	Coefficient	T-Statistic	Probability
Constant	4.573	13.827*	0.000	2.071	12.371*	0.000
$F50_t^-$	0.259	1.417	0.163	0.007	0.076	0.940
$F25_t^-$	-0.025	-2.493**	0.016	0.005	1.068	0.291
$F25_t^+$	-0.009	-1.407	0.166	0.008	2.533**	0.015
$F50_t^+$	0.021	1.822***	0.075	0.003	0.497	0.621
D_t	0.359	1.672***	0.102	-1.262	-11.244*	0.000

Table 3.11: The Effects of both Direction and Magnitude of Repo Rate Announcement Surprise upon Trading Size

Coefficient estimates, t-statistics and associated probabilities of Equation (3.2),

$$MA_t = \alpha_0 + \beta_1 F50_t^- + \beta_2 F25_t^- + \beta_3 F25_t^+ + \beta_4 F50_t^+ + \delta D_t + \varepsilon_i \ ,$$

The dependent variable is the natural log of trade size for the first 5 minutes of post-announcement trading. The independent variables are; $F50_t^-$ is the mean proportion of market participants that forecast a decision of 50 basis points below the actual decision. $F25_t^-$ is the mean proportion of market participants that forecast a decision of 25 basis points below the actual decision. $F25_t^+$ is the mean proportion of market participants that forecast a decision of 25 basis points above the actual decision. $F50_t^+$ is the mean proportion of market participants that forecast a decision of 50 basis points above the actual decision. D_t, is a dummy variable representing the switch to electronic trading. *=significant at the1% level. **=significant at the 5% level. ***=significant at the 10% level. Number of observations=51.

Short Sterling: White Heteroskedasticity Test Statistics: 14.894 (probability=0.094).
LM Test for Serial Correlation Test Statistics: 2.491 (probability=0.288).
Jacque-Bera Test Statistics: 8.448 (probability=0.015).
Adjusted R^2 values=0.163.

FTSE100: White Heteroskedasticity Test Statistics: 6.195 (probability = 0.720).
LM Test for Serial Correlation Test Statistics: 1.611 (probability=0.447).
Jacque-Bera Test Statistics: 0.336 (probability=0.845).
Adjusted R^2 values=0.804.

The results in Table 3.11 indicate that out of all the market participants who incorrectly forecast the repo rate decision, it appears to be only those participants that forecast a decision of 25 basis points above the actual decision are positively related to the trade size for the FTSE100. However for the Short Sterling, those who forecast a decision of 25 basis points below the decision appear to be negatively related to trade size (at the 5% level). In addition the switch to electronic trading appears to be negatively related to trade size for the FTSE 100.

3.4.2.3.4 Diagnostic and Sensitivity Tests

Formal diagnostic tests on the estimated models were also carried out. First, homoskedasticity of the residuals was tested for using White's test. The computed test statistic of trading volume for the FTSE100 (t = 22.296, p= 0.008) means that the hypothesis of homoskedastic errors could not be supported. As a consequence the reported standard errors in Table 3.9 for the FTSE100 are White heteroskedastic-consistent. Serial correlation of the residuals was tested using the Lagrange Multiplier statistic, we found trade frequency of the FTSE100 to be serially correlated (t = 11.128, p = 0.004). We accounted for the serial correlation by the addition of an AR (1) process and this was found to have no adverse effect upon the significance of other explanatory variables. Normality of the residuals was tested using the Jacque-Bera statistic and the null hypothesis of normally distributed errors was rejected for both volume and lnsize of the Short Sterling (t = 10.716, p = 0.005; t = 8.448, p = 0.015 respectively). However, as previously discussed econometric sources such as Kmenta (1971), suggested that non-normal disturbances are common in small data sets and so this limitation is an unavoidable constraint of the research design.

3.5 Summary and Conclusions

In this chapter we examine the impact of repo rate announcements upon both price and trading volume of the Short Sterling and the FTSE 100 futures contracts. In the first section of this chapter we focus on both the price and volume adjustment process to repo rate announcements. Using survey data supplied by Reuters, we separated our announcements into expected announcements and not-expected announcements and focused on an announcement window that extends from two minutes prior to an announcement to the first ten minutes following an announcement. Our results indicate that following a not-expected announcement both contracts initially exhibit large price changes, and raised volatility. For the Short Sterling there is evidence of an initial over-reaction and although mean absolute price changes remain significantly greater than both the respective expected announcement period and the non-announcement period for much of both the first 30 transactions and the first 10 minutes, they rapidly decline at around 120 seconds or 15 transactions. There is evidence of an increased number of larger trades for much of the remainder of the twelve-minute window. For the FTSE100, we found evidence of a delay in reaction following a not-expected announcement. We interpreted this delay as a period where market participants reassessed the announcements' implications upon the futures price. The mean absolute price changes following a not-expected announcement remain significantly greater than both the respective expected announcement period and the non-announcement period for much of both the first 30 transactions and the remainder of the twelve-minute window, although they rapidly decline at around 75 seconds. While both trade frequency and trade size remain elevated for much of the first 10 minutes following a not-expected announcement, trade size remains significantly greater than the respective expected announcement period for only 75 seconds. We interpreted any reaction following an expected announcement as being the result of a minority of market participants that did not expect the announcement decision, and therefore had to trade, as their prior beliefs were not confirmed.

Further, our results indicate a shorter/longer adjustment period following an expected/not-expected announcement than that found following an announcement in Ap

Gwilym et al. (1998). We suggest that the majority of the price adjustment is explained by the degree of surprise associated with an announcement. Therefore in studies such as Ap Gwilym et al. (1998) where announcement data is not split into expected and unexpected components, the observed price adjustment is diluted by the expected components of that announcement. These results further underline the importance of extracting the unexpected components of any announcement if accurate conclusions are to be drawn regarding the adjustment process of futures prices to announcement releases.

While using the difference between the forecast value and the actual announced value as an indicator of whether an announcement is expected or not expected provides a good measure of the consensus of an announcement, it still remains unable to distinguish between what is entirely expected and entirely unexpected information.

In the second section of this chapter we addressed this issue and introduced a new method that captures all elements of surprise associated with each repo rate announcement. We utilised the survey data provided by Reuters to focus on the four possible elements of surprise, these comprised those that forecast a repo rate announcement; 50 basis points below the actual decision, 25 basis points below the decision, 25 basis points above the decision and 50 basis points above the decision. By focusing on the degree of surprise associated with each announcement, we provide a direct test of the impact of entirely unexpected information upon market activity.

We estimated three linear regression equations with our surprise elements as our explanatory variables and trade volume, trade frequency and trade size over the first 5-minutes following an announcement as our dependent variables. Again we focused on trade frequency and trade size for a fuller description of the reaction of volume to new information. Our results indicate that for the Short Sterling, following a repo rate announcement much of the observed first 5-minute volume is a consequence of more frequent trading by those who forecast a repo rate announcement 25 basis points above the actual decision. Those participants who forecast a decision 25 basis points below the actual decision also traded more frequently, but their trades were smaller and so had no impact upon volume. Finally those who forecast a decision 50 basis points below the actual decision were found to trade less often. For the FTSE100, much of the observed first 5-minute volume is a consequence of those who forecast a decision either 25 basis points above or below the actual decision. Those who forecast a decision 25 basis points above the decision were found to trade larger amounts more often compared with those who forecast a decision 25 basis points below the decision who were only found to trade more frequently.

Although much of the volume in the first 5-minutes following an announcement is a consequence of elevated trading activity, by those who forecast a decision 25 basis points either side of the actual decision, one might have expected that following our hypothesis (see section 3.4.2.1), those who forecast a decision 50 basis points either side of the actual decision would have proved to be more significant in explaining the observed elevated market activity following an announcement. However the lack of support for this is a consequence of the small sample sizes within the 50 basis point categories with most of those who forecast incorrectly, being 25 basis points around the actual decision.

Chapter Four

The Price Formation Process in an Order-Driven Market

4.1 Introduction

Central to the market microstructure literature is the notion that in a market with asymmetrically informed agents, trades convey information and through observing the sequence of trades, market participants can update their beliefs. This causes prices to move. Accordingly prices are considered to be a stochastic process conditioned on a function of the trading process. Since the stochastic process of prices forms the foundation of most financial models, it is essential to understand this learning process.

Both theoretical and empirical models have addressed this issue and many features of the trading process have been suggested as informative variables in the price formation process. However an important feature prevalent in most of these models is the existence of a designated market maker who provides bid and ask quotes to the trading public. In the theoretical contribution of Easley and O'Hara (1987), trade size provides information while others such as Garman (1976), Garbade and Lieber (1977), Diamond and Verrecchia (1987) and Easley and O'Hara (1992) indicate that the timing of trades is considered informative. In the empirical literature there has been no clear consensus about the relationship between trading activity and the price formation process. Jones et al. (1994) conclude that the occurrence of transactions per se, and not their size contains all the relevant information required for the pricing of securities. However Huang and Masulis (1999) and Chan and Fong (2000) conclude that trade size provides relevant information. Hasbrouck (1991) found that the change in prices depends on characteristics such as the sign and size of a trade, the market environment as measured by the bid-ask spread and the current and past levels of prices. He suggested the study of time-of-day patterns for a better understanding of the price impact of a trade. Dufour and Engle (2000) extended Hasbrouck's (1991) model to include trade durations (the time between two consecutive transactions) and time-of-day patterns as additional measures of market activity. They found that while trades performed around the open showed some evidence of being significant, in general time-of-day effects were found to be insignificant and concluded that short time durations, hence high trading activity are related to both larger quote revisions and stronger positive autocorrelations of trades. When combined with the earlier results of Hasbrouck (1991), they concluded that higher trading activity is associated with larger spreads, higher volume and higher price impacts of trades. They suggest that when trade size is large or the market is highly active, the liquidity providers revise their beliefs in an upward fashion that an information event has already occurred. This causes them to postpone their trading inferring such markets as having reduced liquidity. Hausman, et al. (1992) estimate ordered probit models for transaction prices. They consider the time between the current trade and the last trade as an explanatory variable, and although time seems to matter, its role appeared inconclusive. Engle and Russell (1994) provide evidence of co-movements among duration, volatility, volume and spread. Engle (1996) observes that longer (shorter) durations lead to lower (higher) volatility.

Other empirical analyses have shown that the dynamics of market variables may be partly attributed to intra-day periodicities. It is well established that quoted bid-ask spreads, volatility and volume exhibit U-shaped patterns over the trading day[1]. However Ederington and Lee (1993) find an L-shape pattern in intra-day volatility for US Treasury Bond, Eurodollar and Deutschmark futures markets, with a peak in volatility early in the day followed by reasonably flat volatility for the rest of the day. They conclude that this peak does not coincide with the market open but rather the release of macroeconomic announcements. Chan et al. (1995) found that the spread of NASDAQ stocks was highest at the beginning of the day, declining thereafter and then narrowing abruptly during the last hour of trading. Reiss and Werner (1993) identified a similar pattern of declining spreads on the London Stock Exchange, which has a multiple dealer structure similar to NASDAQ. Previous studies of intraday behaviour of LIFFE futures markets have reported elevated volume and volatility around the release of macroeconomic announcements as well as around the market open and close. Becker et al. (1995a) find that the volatility of 30-minute returns for the FTSE 100 index futures market responds to the release of UK and US economic data. Becker et al. (1993) find elevated volatility in the Long Gilt futures market following UK and US announcements. Becker et al. (1995b) report that volatility for the Long Gilt, Short Sterling and other contracts traded on LIFFE is elevated around times of UK and US announcements. Abhyanker et al. (1999) examine the intraday behaviour of returns, returns volatility, traded volume and bid-ask spreads for the FTSE 100 futures contracts and found U-shaped patterns in both volume and volatility, however in contrast to the behaviour reported in many studies of US futures markets, they found high spreads at the open with a steady rise to mid-day then falling thereafter with a particularly sharp drop just before the market close. Buckle et al. (1998) examine the intraday behaviour of returns, returns volatility, trading volume, reversals, and returns autocorrelation for the FTSE 100 and the Short Sterling futures contracts. For both contracts they report U-shaped patterns in volatility and volume but where the variables are higher at the open than the close. For the FTSE 100 they reported elevated volatility following UK and US announcements, in contrast for the Short Sterling they only reported elevated volatility following UK announcements. Engle and Russell (1998) indicated that trade durations exhibit an inverted U-shaped pattern over the trading day.

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[1] See Wood et al (1985), Harris (1986), Jain and Joh (1988), McInish and Wood (1992), Brock and Kleidon (1992), Eckman (1992), Laux (1993), Wang et al. (1994).

In this chapter, we examine the price learning process of the FTSE100 futures contract; that is we examine the information content of its trades and evaluate how these are reflected in the market quotes. An important distinction between this study and others is that in our work we consider an order-driven market, where there is no market maker. In an order driven market traders can enter either limit orders or market orders. A limit order is an order to buy/sell a given quantity at a maximum/minimum price within a given time horizon. A market order is an order to buy/sell a given quantity at the best available price. In an order driven market transactions occur when orders are matched, and the spread amounts to the difference between the smallest limit sell price and the largest limit buy price. Indeed the traders who enter limit orders provide liquidity to those who enter market orders, in a similar way to market makers providing liquidity in a quote driven market.

Using Hasbrouck's (1991) Vector Autoregression (VAR) model, we extend this model in a similar manner to that of Dufour and Engle (2000) to incorporate time as an additional feature of the price formation process. We argue that such models can be extended to markets where limit orders rather than a specialist provide liquidity. In the literature a few studies have documented that there is no fundamental difference between a specialist market and an order driven market, in the sense that the same set of equilibrium prices will be obtained in either market (see Tonks (1998) and Dufour and Engle (2000)). By applying their methodology to an order driven market we gain further insight into the dynamic process of price formation in an order-driven market. Moreover this provides for a comparative analysis of the price formation process in these two types of markets. Finally by incorporating time into the price formation process we provide additional evidence of the role played by time, which has only recently been considered an important feature in market microstructure.

This study is organised as follows, in Section 4.2 we introduce the data used in this chapter. In Section 4.3 we introduce our model. In Section 4.4 we discuss the results, while focusing on price formation in order-driven markets and in particular the information content of time in models for price and trade dynamics. In Section 4.5 we summarise our findings and conclusions.

4.2 Data and Methodology

4.2.1 LIFFE Data

Again we use transaction data provided by LIFFE for the FTSE100 futures contract. The data includes details of all trades, bids and asks to the nearest second, delivery month, price and volume. We use the nearest-to-maturity contract until the trading volume on the next contract becomes greater. This generally occurs at maturity. The sample period is January 4, 2000 to June 30, 2000.

4.2.2 Preparation of the Data for the Analysis

We prepare the data for our analysis as follows. First, we only consider trades, asks and bids that occur between 08:35:00GMT and 16:30:00GMT. Secondly, we filter out any anomalous data[2]. Thirdly, we add up the volume of consecutively recorded trades that occur at the same timestamp and the same price, and we consider these as one trade. Fourthly, we omit the opening trade and the overnight price change to avoid contamination of prices by the arrival of overnight news. Hence we drop transactions occurring before the first quote and treat the overnight price change as a missing value for all lagged variables. Despite these adjustments the data set still remains very large, with 804,555 observations.

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[2] We deleted three unusual transactions reported on the 02/03/00 and the 31/03/00. Reasons for these included the collapsing of the electronic trading system.

4.3 The Model

Under the hypothesis that the public information set is exclusively given by the past evolution of trades and quotes, Hasbrouck (1991) introduced an econometric methodology to model the dynamic relationship between the trading process and the subsequent adjustment of market quotes. This methodology is based on a general VAR model for the changes of the quote midpoint and the trade indicator. Following Dufour and Engle (2000) we use a generalisation of the Hasbrouck (1991) model to include time as a predetermined variable that influences both the price impact of a trade and the correlation between trades. This presents the following system for quote revisions and trades in an order-driven market,

$$r_t = \sum_{i=1}^{5} a_i r_{t-i} + \sum_{i=0}^{5} [\gamma_i^r + \sum_{j=1}^{15} \lambda_{j,i}^r D_{j,t-i} + \delta_i^r \ln(T_{t-i})] x_{t-i}^0 + v_{1,t}$$

$$x_t^0 = \sum_{i=1}^{5} c_i r_{t-i} + \sum_{i=1}^{5} [\gamma_i^x + \sum_{j=1}^{15} \lambda_{j,i}^x D_{j,t-i} + \delta_i^x \ln(T_{t-i})] x_{t-i}^0 + v_{2,t} \qquad (4.1)$$

Using the familiar rule of using t to index trades. We define the revision in quotes, r_t as the change in the natural logarithm of the mid-quote price that follows the current trade at time t, so that $r_t = \ln (q_t - q_{t-1})$. To examine the role of time we consider time durations, T_t, the difference in seconds between the time stamp for the trade x_t and the previous trade x_{t-1}, and a set of time-of-day dummy variables $D_{j,t-i}$ Without loss of generality we add one second to each trade duration observation, so that the lowest log-duration is zero. We consider 15 diurnal dummy variables. We present these dummy variables and their respective time intervals in Table 4.1 below. In particular we focus on the UK open and close, as well as the US open[3] and the UK and US announcement effect.

[3] The US open is generally 13:20GMT, however due to British DST (daylight saving time), for trading days that occur between 26/03/00 and 01/04/00, the US open is 14:20 GMT.

We use a dummy variable x_t^0, which indicates the direction of the trade[4]. This variable assumes a value of one if the trade is initiated by a buyer, a value of minus one if the trade is initiated by a seller and zero if the trade is just a match of two opposite orders at the mid-quote. Since we do not have any information on the actual identity of the trade initiator, we determine the direction of a trade based on the prevailing quote. We classify a trade as a purchase if the transaction price equals the price of the last ask, as a sale if the transaction price equals the price of the last bid and unclassified if the transaction price is equal to the mid-quote price. This procedure results in classifying 48.35 % as buyer initiated, 50.55 % as seller initiated and leaves a residual of 1.10 % as unclassified. We delete these unclassified trades.

Although it is unusual to include a limited dependent variable in a vector autoregression, this presents no econometric difficulties when it is as an explanatory variable, which is the case for the relationship of primary interest, the price equation. However when estimating the trade equation, the linear specification is potentially inappropriate. Nonetheless, OLS estimation still yields consistent parameter estimates, if the conditional mean of the trade indicator is correctly specified. However with the probability of a buy or sell being so close to 0.5, the linear specification is acceptable.

Additionally the informational component of price variation can be related to two different sources of information, public and private. These informational shocks are commonly represented by two white noise processes $v_{1,t}$ and $v_{2,t}$. Where $v_{1,t}$ represents the update to public information and $v_{2,t}$ captures the unanticipated component of the trade (relative to an expectation formed from linear projection on the trade and quote revision history). As such if there is any new information contained in x_t it must reside in the innovation $v_{2,t}$, since the remaining component is entirely known. This does not imply that the innovation is a deterministic function of the new information. The presence of uninformed liquidity traders, for example will introduce a noise component of $v_{2,t}$ that is uncorrelated with private information. Assuming that public information prior to the tth trade does not aid the forecast of future innovations, model (4.1) may be

[4] Hasbrouck (1991) also suggests generalisations with x_t as a vector of other trade related variables such as the interaction between trade sign and volume and the interaction between trade sign and spread.

estimated with the current trade in the first equation and the further assumption that the disturbances have zero means and are jointly and serially uncorrelated.

Hasbrouck (1991) suggests that as many microstructure imperfections can cause lagged effects to new information, a more robust model would be achieved by including lagged values[5]. Although in principle this may be of an infinite order, for practical purposes it is truncated at some finite lag. We assume that summations in model (4.1) can be truncated at 5 lags and the model can be estimated consistently by ordinary least squares (OLS)[6].

Dummy Variable	Time Interval
1	08:35:00 - 08:44:59
2	08:45:00 - 08:59:59
3	09:00:00 - 09:59:59
4	10:00:00 - 10:59:59
5	11:00:00 - 11:59:59
6	12:00:00 - 12:59:59
7	12:00:00 - 12:04:59
8	13:00:00 - 13:19:59
9	13:20:00 - 13:29:59
10	13:30:00 - 13:34:59
11	13:35:00 - 13:59:59
12	14:00:00 - 14:59:59
13	15:00:00 - 15:59:59
14	16:00:00 - 16:14:59
15	16:15:00 - 16:29:59

Table 4.1: The Diurnal Dummy Variables and their Respective Time Intervals

In particular D_3 represents trades performed around the U.K. announcements. D_6 represents the lunch hour. D_7 represents the repo announcement effect. D_9 represents the first ten minutes of trading after the U.S. open. D_{10} represents the first five minutes of trading after the U.S. announcements are released.

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[5] The estimation error in the VAR approach is due to the truncation of the autoregressions, and with longer lags a better accuracy is achieved. Hasbrouck (1991) indicate that quotes adjust rapidly and after 5 transactions the majority of the adjustment is complete. Subsequently Dufour and Engle (2000) followed Hasbrouck (1991) and truncate to 5 lags.

[6] Covariance stationarity of the price trade process is typically assumed (see Hasbrouck (1991), de Jong et al. (1995) and Dufour and Engle (2000)).

4.4 Empirical Results

4.4.1 Time-of-Day Effects

In this section we follow the suggestion raised in Hasbrouck (1991) and study whether the time of day plays an important role in the price formation process. Although Dufour and Engle (2000) only found evidence of trades performed in the first 30 minutes of the trading day to be significant, we indicated in Section 4.1 that other previous empirical analyses have shown that dynamics of market variables may be attributed partly to intra-day periodicities. It follows that time-of-day effects may be informative considerations to the dynamic process of price formation for the futures markets.

We estimate the VAR defined by model (4.1), with current and lagged values of all but one of the diurnal dummy variables[7]. Firstly we perform a Wald test of the null that all lagged diurnal dummies are jointly zero. Since heteroskedasticity is present in the residuals for the quote equation[8] we use White's heteroskedasiticity consistent covariance estimator to compute both Wald and *t*-statistics. Since both heteroskedasticity and autocorrelation are present in the residuals of the trade equation[9], we use the Newey-West estimator that is consistent in the presence of both heteroskedasticity and autocorrelation of unknown form, to compute both Wald and *t*-statistics. We reject the null that all lagged diurnal dummies are jointly zero, for both the quote revision equation and the trade equation, with respective *p*-values of 0.000 and 0.000.

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[7] When all dummy variables are included in the estimation, we encounter multicollinearity. For this purpose we drop D_{13}, which considers trades that occur between 15:00 and 16:00 GMT.

[8] White Heteroskedasticity Test Statistic: 71.714 (probability = 0.000)

[9] White Heteroskedasticity Test Statistic: 12.129 (probability = 0.000),
LM Test for Serial Correlation Test Statistic: 370.785 (probability = 0.000)

We then exclude from the model all insignificant lagged diurnal dummies and when re-estimating the VAR we see little effect of this exclusion on both the coefficients and t-statistics of the remaining market variables. Therefore we re-estimate the VAR with only the significant current and lagged diurnal dummies.

4.4.2 The Trade Equation

Table 4.2 presents the estimated coefficients for the trade equation. We format in bold the values of the coefficients that are significantly different from zero at the 5 percent level of confidence. Since both heteroskedasticity and autocorrelation are present in the residuals[10], we use the Newey-West estimator to compute both Wald and t-statistics.

The coefficients on lagged price changes are positive for the first leading lag but negative at the next two leading lags. This indicates that when quotes are revised in an upward fashion more buyers enter the market and similarly when quotes are revised in a downward fashion more sellers enter the market. In contrast Hasbrouck (1991) and Dufour and Engle (2000) found negative lagged quote revisions at all leading lags in the trade equation. They indicated that these findings might be the consequence of inventory control effects since a monopolistic market maker with an inventory surplus would reduce quotes to encourage more purchases. In addition we found signed trades exhibit strong positive autocorrelation. This is consistent with the findings of Hasbrouck and Ho (1987), Hasbrouck (1988), Hasbrouck (1991) and more recently Dufour and Engle (2000), the explanation is simply that purchases tend to follow purchases and sales tend to follow sales. Hasbrouck (2000) further describes the short-run predominance of positive auto-correlation to be consistent with a lagged adjustment to new information.

The coefficients of the dummy variables for trades performed around the U.K. announcement time and trades performed around the end of day are positive and significant and negative and significant respectively at the first lag. Although the

[10] White Heteroskedasticity Test Statistic: 38.927 (probability = 0.000),
LM Test for Serial Correlation Test Statistic: 369.046 (probability = 0.000)

coefficients for other announcement dummies are significant, including trades performed around both the U.K. and the U.S. opening time, we shall not focus on these, as these do not occur at the leading lags. However in brief, trades performed during the first ten minutes after the open and trades performed during the next fifteen minutes were found to be positive and significant at the second lag. Trades performed around the U.S. open and the end of day was found to be negative and significant at the third lag. Trades performed following both the U.S. open and the U.S. announcements were found to be negative and significant at lag 5.

The δ_i coefficients that represent the interaction between the trade indicator and trade duration, are typically positive and significant for the first four lags. These findings are in contrast to Dufour and Engle (2000), while they found time durations to be significant for 13 out of 18 stocks at the first leading lag. For 8 of these 13 coefficients the sign was negative.

Thus we conclude that although time effects in the trade equation appear partly attributable to daily periodicities they are primarily due to the stochastic component of time durations T_t. This interpretation is confirmed by the results of tests on time coefficients presented in Table 4.3. The first column of Table 4.3 presents Wald statistics for the null hypothesis that time coefficients are jointly zero. We reject the null hypothesis. In the last two columns of Table 4.3 we show respectively Wald statistics for the null hypothesis that all δ_i coefficients are jointly zero and that the sums of these coefficients are jointly zero. We reject the null hypothesis that all are jointly zero and that the sum of the δ_i coefficients is zero.

Lag Quote Revision		Lag Trade		Lag Trade Lag Duration		Lag Trade Lag Diurnal Dummy $i=1$		$i=2$		$i=3$		$i=5$		Adj.R^2
c_1	**2.022150**	γ_1	**0.222556**	δ_1	**0.019564**	λ_3	**0.010449**	λ_1	**0.025101**	λ_9	**-0.030032**	λ_6	-0.007931	0.100
	(12.625)		**(108.441)**		**(16.694)**		**(3.088)**		**(3.523)**		**(-2.979)**		(-1.901)	
c_2	**-2.073912**	γ_2	**0.064459**	δ_2	**0.016442**	λ_{15}	**-0.017882**	λ_2	**0.013201**	λ_{15}	**-0.019195**	λ_9	**-0.021309**	
	(-13.446)		**(33.162)**		**(14.151)**		**(-3.767)**		**(2.254)**		**(-4.111)**		**(-2.308)**	
c_3	**-0.254385**	γ_3	**0.037921**	δ_3	**0.010041**							λ_{11}	**-0.013502**	
	(-2.411)		**(19.376)**		**(8.587)**								**(-2.628)**	
c_4	-0.093276	γ_4	**0.030061**	δ_4	**0.005040**									
	(-0.901)		**(15.912)**		**(4.309)**									
c_5	-0.112430	λ_5	**0.033899**	δ_5	-0.000181									
	(-1.152)		**(18.317)**		(-0.156)									

Table 4.2: Trade Equation in the Vector Autoregression

Coefficient estimates and t-statistics for the trade equation.

$$x_t^0 = \sum_{i=1}^{5} c_i r_{t-i} + \sum_{i=1}^{5} [\gamma_i^x + \sum_{j=1}^{15} \lambda_{j,i}^x D_{j,t-i} + \delta_i^x \ln(T_{t-i})] x_{t-i}^0 + v_{2,t}.$$

T_t is the time interval between two consecutive transactions; x_t^0 is the trade indicator (1 for a buyer; -1 for a seller). r_t is the quote revision following transaction t. The t-statistics (in parentheses) are computed using Newey-West adjustment. The sample covers the period from 4 January 2000 to 30 June 2000. For simplicity we present the general model above, however for the model that we used to obtain the above results we only considered the significant diurnal dummy variables. Bold format denotes significance at the 5 percent level.

Diurnal and Stochastic Components	Stochastic Component	
$H_0: \lambda_{j,i} = \delta_i = 0 \quad (i = 1,\ldots,5)$	$\delta_i = 0 \quad (i = 1,\ldots,5)$	$\sum_{i=1}^{5} \delta_i = 0$
Wald Test	Wald Test	$100 * \sum_{i=1}^{5} \delta_i$
722.635	**606.848**	**5.091**

Table 4.3: The Significance of Time in the Trade Equation.

Wald and t-tests on the significant diurnal dummies and δ_i coefficients in the trade equation

$$x_t^0 = \sum_{i=1}^{5} c_i r_{t-i} + \sum_{i=1}^{5} [\gamma_i^x + \sum_{j=1}^{15} \lambda_{j,i}^x D_{j,t-i} + \delta_i^x \ln(T_{t-i})] x_{t-i}^0 + v_{2,t}$$

T_t is the time interval between two consecutive transactions; x_t^0 the trade indicator (1 for a buyer; -1 for a seller). r_t is the quote revision following transaction t. Wald and t-statistics are computed using Newey-West adjustment. The sample covers the period from 4 January 2000 to 30 June 2000. For simplicity we present the general model above, however for the model that we used to obtain the above results we considered only the significant diurnal dummy variables. Bold format denotes significance at the 5 percent level

4.4.3 The Quote Revision Equation

Table 4.4 presents the estimated coefficients for the quote revision equation. We format in bold the values of the coefficients that are significantly different from zero at the 5 percent level of confidence. Since both heteroskedasticity and autocorrelation are both presents in the residuals[11], we use the Newey-West estimator to compute both Wald and t-statistics.

The coefficients on lagged price changes are positive for all lags indicating positive correlation in returns. This indicates a high level of continuations, and is consistent with the observed declining futures price over our time period. More specifically the futures

[11] White Heteroskedasticity Test Statistic: 162.414 (probability = 0.000),
LM Test for Serial Correlation Test Statistic: 5.120 (probability = 0.000)

price was around 6930 in early January 2000 and 6359 at the end of June 2000. The central coefficients to this study are the γs and the δ's which represent the coefficients of the trade indicator and the interaction of the trade indicator and trade duration respectively. These coefficients reveal the price impact of a signed trade. By examining these coefficients we observe that the price impact of a signed trade is positive at the current value but negative and generally decreasing at all lags, and negatively related to durations. More specifically the coefficient of x_t^0 implies that on average the quote midpoint is raised roughly 1.004 immediately subsequent to a purchase order.

The coefficients on the interaction between the trade indicator and trade durations are negative and significantly different from zero for the current and the first two leading lags. We interpret this in a similar fashion to Dufour and Engle (2000), "*A buy transaction arriving after a long time interval has a lower price impact than a buy transaction arriving right after a previous trade*". We conclude that with trade frequency being higher, hence trade duration being lower then the market infers a higher likelihood of informed traders. This presence of informed traders may further deter the uninformed from trading. Therefore it becomes increasingly difficult for liquidity traders to enter the market and match the opposite side of a trade hence trades have a larger price impact.

The coefficient estimates of the diurnal dummy variables indicate that eleven out of the fourteen dummies are both positive and significant at the current lag, and ten out of the fourteen dummies are significant at the first lag. These first lag diurnal dummies however are generally negative with the exception of trades performed during the last fifteen minutes of the trading day, which shows a positive sign. Trades performed during both lunchtime and the last fifteen minutes of the trading day were negative and significant and positive and significant respectively at the second lag. Trades performed during the last fifteen minutes of the day were positive and significant at lag 3. Finally trades performed between both 11:00 and 12:00 and prior to the U.S. announcements were found to be both negative and significant at lag 5. These findings differ from those reported in Dufour and Engle (2000) where time-of-day effects were found to be generally insignificant in the quote revision equation, with some evidence of trades performed around the open to be significant.

However in consensus with many earlier findings of the importance of including time-of-day effects in models of market microstructure, we show in particular that the opening of the UK and US market, the release of UK and US macroeconomic announcements, the lunch-time effect and the market close to be highly significant variables in the quote-revision equation of the market considered in this study.

Thus time effects in the quote equation appear attributable to both daily periodicities and the stochastic component of trade durations T_t. This interpretation is again confirmed by the results of tests on time coefficients presented in Table 4.5. The first column of Table 4.5 presents Wald statistics for the null hypothesis that all time coefficients are jointly zero. We reject the null hypothesis. In the last two columns of Table 4.5 we show respectively Wald statistics for the null hypothesis that all δ_i coefficients are jointly zero and that the sums of these coefficients are jointly zero. We reject the null hypothesis that all are jointly zero and that the sum of the δ_i coefficients is zero.

Lag Quote Revision		Lag Trade		Lag Trade Lag Duration		Lag Trade Lag Diurnal Dummy										Adj.R^2
						$i=0$		$i=1$		$i=2$		$i=3$		$i=5$		
a_1	**0.337788**	γ_0	**0.004251**	δ_0	**-0.000310**	λ_1	**0.000676**	λ_2	**-0.000458**	λ_6	**-0.000134**	λ_{15}	**0.000184**	λ_5	**-0.000096**	
	(24.828)		**(78.964)**		**(-8.015)**		**(5.878)**		**(-4.187)**		**(-2.630)**		**(3.097)**		**(-2.310)**	
a_2	**0.041292**	γ_1	**-0.000346**	δ_1	**-0.000230**	λ_2	**0.001013**	λ_3	**-0.000376**	λ_{15}	**0.000175**			λ_8	**-0.000247**	
	(10.542)		**(-6.282)**		**(-16.470)**		**(9.697)**		**(-8.161)**		**(3.132)**				**(-3.153)**	
a_3	**0.019893**	γ_2	**-0.000402**	δ_2	**-0.000028**	λ_3	**0.000760**	λ_4	**-0.000306**							
	(8.171)		**(-15.059)**		**(-2.107)**		**(12.666)**		**(-6.103)**							
a_4	**0.012353**	γ_3	**-0.000212**	δ_3	-0.000017	λ_4	**0.000657**	λ_5	**-0.000485**							
	(5.929)		**(-8.858)**		(-1.227)		**(10.722)**		**(-9.742)**							
a_5	**0.004915**	γ_4	**-0.000150**	δ_4	0.000002	λ_5	**0.000963**	λ_6	**-0.000544**							
	(2.303)		**(-6.647)**		(0.146)		**(14.687)**		**(-8.950)**							
		γ_5	**-0.000082**	δ_5	0.000002	λ_6	**0.001397**	λ_8	**-0.000693**							0.257
			(-3.802)		(0.127)		**(18.109)**		**(-7.203)**							
						λ_8	**0.001398**	λ_9	**-0.000465**							
							(11.817)		**(-3.256)**							
						λ_9	**0.001515**	λ_{11}	**-0.000209**							
							(9.103)		**(-3.305)**							
						λ_{10}	**0.001109**	λ_{12}	**-0.000154**							
							(5.235)		**(-3.935)**							
						λ_{11}	**0.000398**	λ_{15}	**0.000133**							
							(4.690)		**(2.067)**							
						λ_{12}	**0.000130**									
							(2.520)									

Table 4.4: The Quote Revision Equation in the Vector Autoregression.

Coefficient estimates and t-statistics for the trade equation.

$$r_t = \sum_{i=1}^{5} a_i r_{t-i} + \sum_{i=0}^{5} [\gamma_i^r + \sum_{j=1}^{15} \lambda_{j,i}^r D_{j,t-i} + \delta_i^r \ln(T_{t-i})] x_{t-i}^0 + v_{1,t}.$$

T_t is the time interval between two consecutive transactions; x_t^0 is the trade indicator (1 for a buyer; -1 for a seller). r_t is the quote revision following transaction t. The t-statistics (in parentheses) are computed using Newey-West adjustment. The sample covers the period from 4 January 2000 to 30 June 2000. For simplicity we present the general model above, however for the model that we used to obtain the above results we only considered the significant diurnal dummy variables. Bold format denotes significance at the 5 percent level.

Diurnal and Stochastic Components	Stochastic Component	
$H_0: \lambda_{j,i} = \delta_i = 0 \quad (i = 0,\ldots,5)$	$\delta_i = 0 \quad (i = 0,\ldots,5)$	$\sum_{i=0}^{5} \delta_i = 0$
Wald Test	Wald Test	$10000 * \sum_{i=0}^{5} \delta_i$
1397.909	**447.573**	**-5.810**

Table 4.5: The Significance of Time in The Quote Revision Equation

Wald and t-tests on the significant diurnal dummies and δ_i coefficients in the quote revision equation

$$r_t = \sum_{i=1}^{5} a_i r_{t-i} + \sum_{i=0}^{5} [\gamma_i^r + \sum_{j=1}^{15} \lambda_{j,i}^r D_{j,t-i} + \delta_i^r \ln(T_{t-i})] x_{t-i}^0 + v_{1,t}$$

T_t is the time interval between two consecutive transactions; x_t^0 is the trade indicator (1 for a buyer; -1 for a seller). r_t is the quote revision following transaction t. Wald and t-statistics are computed using Newey-West adjustment. The sample covers the period from 4 January 2000 to 30 June 2000. For simplicity we present the general model above, however for the model that we used to obtain the above results we only considered the significant diurnal dummy variables. Bold format denotes significance at the 5 percent level.

4.4.4 Robustness of Results for Time

At present, our results indicate that trade durations plays a significant role in the dynamic relationship of both quote revision and trades. However, as we discussed in Section 4.1 many other features of the trading process have been indicated as informative variables in the dynamics of price formation. It follows that the time between transactions may not offer any new information other than that conveyed by such features as volume and spread. Dufour and Engle (2000) examined this proposition and while they found both volume and spread predominantly characterised the price impact of trades and the effect of trade durations was only marginal, time was more robust in the trade equation with 10 out of the 18 stocks indicating trade durations as significant.

In a similar manner we examine whether trade durations are important determinants of both price and trade dynamics or whether, other features such as volume and spread are more informative variables. By adding these variables to both the trade impact and autocorrelation of trades we have

$$r_t = \sum_{i=1}^{5} a_i r_{t-i} + \sum_{i=0}^{5}\sum_{j=1}^{15} \lambda_{j,i}^{x} D_{j,t-i} x_{t-i}^{0} + \sum_{i=0}^{5} b_i x_{t-i}^{0} + v_{1,t},$$

$$x_t^0 = \sum_{i=1}^{5} c_i r_{t-i} + \sum_{i=1}^{5}\sum_{j=1}^{15} \lambda_{j,i}^{x} D_{j,t-i} x_{t-i}^{0} + \sum_{i=1}^{5} d_i x_{t-i}^{0} + v_{2,t}, \tag{4.2}$$

where the trade impact on quote revisions (b_i) and trades (d_i) is parameterised as

$$(b_i, d_i) = \gamma_i + \delta_{1,i} \ln(T_{t-i}) + \delta_{2,i} \ln(Vol_{t-i}) + \delta_{3,i} Spread_{t-i}, \tag{4.3}$$

Where *vol* is defined as the trade volume, and *spread* is defined as the difference between the last ask and the last bid prices.

Table 4.6 presents the estimated coefficients for the trade equation and Table 4.8 presents the estimated coefficients for the quote revision equation. We format in bold the values of the coefficients that are significantly different from zero at the 5 percent level of confidence. Since both heteroskedasticity and autocorrelation are present in the residuals of both the trade equation[12] and the quote revision[13] equation we use the Newey-West estimator to compute the standard errors. Our results indicate that when we add both volume and spread to trade duration as determinants of both price and trade dynamics we found that for the trade equation trade durations still enters as positive and significant for the first four leading lags, while trade durations in the quote revision equation still enters as negative and significant at the current and first leading lag.

[12] White Heteroskedasticity Test Statistic: 315.341 (probability = 0.000),
LM Test for Serial Correlation Test Statistic: 372.326 (probability = 0.000).

[13] White Heteroskedasticity Test Statistic: 269351.5 (probability = 0.000),
LM Test for Serial Correlation Test Statistic: 11.031 (probability = 0.000).

We also found that while trade durations for both equations were robust to the presence of volume and spread, both of these additional variables are important determinants of both price and trade dynamics in the order-driven market considered here. For the trade equation we found both volume and spread to be generally positive and significant. For the quote revision equation we found spread to be positive and significant at the current lag and generally negative and significant at the remaining leading lags, whereas volume was also positive and significant at the current lag and negative and significant at the first leading lag however for the remaining leading lags volume was generally insignificant. These interpretations are confirmed by the results of tests on the coefficients, of these three market variables.

We perform two tests on each group of coefficients related to trade durations, volume and spread. First we test the null that all coefficients in each group are jointly zero and after computing their sum we also test that the sum is zero. The sum of the coefficients for each group provides a first raw approximation of the long-run impact on both price and trade dynamics of the specific explanatory variable. We present the results of the trade equation in Table 4.7 and the results of the quote revision equation in Table 4.9. Our results indicate that for the trade equation, all three variables exhibit a positive and significant long-run impact of signed trades, for the quote revision equation trade durations exhibit a negative long-run impact on prices while both trade volume and spread exhibit a positive impact on prices.

Further, daily variation appeared generally robust to the addition of both volume and spread for both equations. Although we do not report the diurnal dummy coefficients and their respective *t*-statistics, we note there was generally very little change in both the coefficients and their respective *t*-statistics compared to those shown in Table 4.2 and Table 4.4 [14].

[14] With exception to the quote revision equation where both $\lambda_{10,0}$ and $\lambda_{15,1}$ are now insignificant.

Quote Revision		Lag Trade		Lag Trade Lag Duration		Lag Trade Lag Volume		Lag Trade Lag Spread		Adj. R^2
c_1	**1.805311**	γ_1	**0.200389**	$\delta_{1,1}$	**0.019159**	$\delta_{2,1}$	-0.000111	$\delta_{3,1}$	**0.014647**	0.101
	(9.088)		**(30.433)**		**(15.292)**		(-0.087)		**(3.706)**	
c_2	**-2.091773**	γ_2	**0.056569**	$\delta_{1,2}$	**0.019449**	$\delta_{2,2}$	**0.017349**	$\delta_{3,2}$	-0.005072	
	(-11.512)		**(10.696)**		**(15.962)**		**(14.210)**		(-1.564)	
c_3	**-0.307652**	γ_3	**0.023763**	$\delta_{1,3}$	**0.012344**	$\delta_{2,3}$	**0.012546**	$\delta_{3,3}$	**0.002094**	
	(-2.786)		**(9.209)**		**(10.485)**		**(10.265)**		**(2.051)**	
c_4	-0.135079	γ_4	**0.016666**	$\delta_{1,4}$	**0.006734**	$\delta_{2,4}$	**0.008160**	$\delta_{3,4}$	**0.003594**	
	(-1.268)		**(6.469)**		**(5.709)**		**(6.740)**		**(3.514)**	
c_5	**-0.233760**	γ_5	**0.0126365**	$\delta_{1,5}$	0.000923	$\delta_{2,5}$	**0.006222**	$\delta_{3,5}$	**0.007788**	
	(-2.213)		**(5.743)**		(0.791)		**(5.131)**		**(6.122)**	

Table 4.6: Robustness of Results on Time for the Trade Equation

The coefficients of the trade equation

$$x_t^0 = \sum_{i=1}^{5} c_i r_{t-i} + \sum_{i=1}^{5}\sum_{j=1}^{15} \lambda_{j,i}^x D_{j,t-i} x_{t-i}^0 + \sum_{i=1}^{5} d_i x_{t-i}^0 + v_{1,t},$$

where b_i is the parameterised as

$$d_i = \gamma_i + \delta_{1,i} \ln(T_{t-i}) + \delta_{2,i} \ln(Vol_{t-i}) + \delta_{3,i}\, Spread_{t-i}.$$

r_t is the quote change after the trade t, x_t^0 is the trade indicator (1for a buy; -1 for a sell). T_t is the time between two consecutive transactions (+ 1second). *Vol* is the number of futures contracts traded. *Spread* is the difference between the last ask and the last bid price. For simplicity we present the general model above, however for the model that we used to obtain the above results we considered only the significant diurnal dummy variables. The sample covers the period from the 4 January 2000 to 30 June 2000. We used Newey-West adjustment that is consistent in the presence of both heteroskedasticity and autocorrelation of unknown form to compute t-statistics. Bold format denotes significance at the 5 percent level.

Time Duration			Volume			Spread		
$H_0: \delta_{1,i}$ jointly zero	$\sum \delta_{1,i}$	$H_0: \sum \delta_{1,i} = 0$	$H_0: \delta_{2,i}$ jointly zero	$\sum \delta_{2,i}$	$H_0: \sum \delta_{2,i} = 0$	$H_0: \delta_{3,i}$ jointly zero	$\sum \delta_{3,i}$	$H_0: \sum \delta_{3,i} = 0$
$\Pr ob > \chi^2$		$\Pr ob > \chi^2$	$\Pr ob > \chi^2$		$\Pr ob > \chi^2$	$\Pr ob > \chi^2$		$\Pr ob > \chi^2$
0.0000	0.0586	**0.0000**	**0.0000**	**0.0442**	**0.0000**	**0.0000**	**0.0231**	**0.0000**

Table 4.7: Significance of Time in the Presence of Volume and Spread for the Trade Equation

The coefficients of the trade equation

$$x_t^0 = \sum_{i=1}^{5} c_i r_{t-i} + \sum_{i=1}^{5} \sum_{j=1}^{15} \lambda_{j,i}^x D_{j,t-i} x_{t-i}^0 + \sum_{i=1}^{5} d_i x_{t-i}^0 + v_{1,t},$$

where b_i is the parameterised as

$$d_i = \gamma_i + \delta_{1,i} \ln(T_{t-i}) + \delta_{2,i} \ln(Vol_{t-i}) + \delta_{3,i} \, Spread_{t-i}.$$

r_t is the quote change after the trade t, x_t^0 is the trade indicator (1 for a buy; -1 for a sell). T_t is the time between two consecutive transactions (+ 1second). *Vol* is the number of futures contracts traded. *Spread* is the difference between the last ask and the last bid price. For simplicity we present the general model above, however for the model that we used to obtain the above results we considered only the significant diurnal dummy variables. The sample covers the period from the 4 January 2000 to 30 June 2000. We used Newey-West adjustment that is consistent in the presence of both heteroskedasticity and autocorrelation of unknown form to compute Wald statistics. We consider each group of coefficients and test the null hypothesis that these δ_i coefficients are jointly zero. We also compute the sum of these coefficients and then test the null hypothesis that this sum equals zero. The tail probabilities for the Wald statistics are computed. Bold format denotes significance at the 5 percent level.

Quote Revision		Lag Trade		Lag Trade Lag Duration		Lag Trade Lag Volume		Lag Trade Lag Spread		Adj. R^2
c_1	**0.341864**	γ_0	0.001219	$\delta_{1,0}$	**-0.000261**	$\delta_{2,0}$	**0.000958**	$\delta_{3,0}$	**0.001525**	0.280
	(44.331)		(1.516)		**(-4.613)**		**(34.496)**		**(2.596)**	
c_2	**0.041943**	γ_1	0.000640	$\delta_{1,1}$	**-0.000141**	$\delta_{2,1}$	**-0.000045**	$\delta_{3,1}$	**-0.000768**	
	(13.209)		(1.594)		**(-4.563)**		**(-2.426)**		**(-2.615)**	
c_3	**0.019036**	γ_2	**-0.000248**	$\delta_{1,2}$	-0.000013	$\delta_{2,2}$	0.000013	$\delta_{3,2}$	**-0.000010**	
	(8.485)		**(-4.872)**		(-0.912)		(0.883)		**(-3.265)**	
c_4	**0.012679**	γ_3	**-0.000179**	$\delta_{1,3}$	-0.000013	$\delta_{2,3}$	-0.000013	$\delta_{3,3}$	-0.000009	
	(6.070)		**(-5.696)**		(-0.992)		(-0.896)		(-0.588)	
c_5	**0.006265**	γ_4	-0.000044	$\delta_{1,4}$	0.000001	$\delta_{2,4}$	**-0.000038**	$\delta_{3,4}$	**-0.000050**	
	(2.869)		(-1.286)		(0.046)		**(-2.691)**		**(-2.778)**	
		γ_5	0.000022	$\delta_{1,5}$	0.000001	$\delta_{2,5}$	-0.000027	$\delta_{3,5}$	**-0.000057**	
			(0.738)		(0.078)		(-1.926)		**(-3.629)**	

Table 4.8: Robustness of Results on Time for the Quote Revision Equation

The coefficients of the trade equation

$$r_t = \sum_{i=1}^{5} a_i r_{t-i} + \sum_{i=0}^{5}\sum_{j=1}^{15} \lambda^x_{j,i} D_{j,t-i} x^0_{t-i} + \sum_{i=0}^{5} b_i x^0_{t-i} + v_{1,t},$$

where b_i is the parameterised as

$$b_i = \gamma_i + \delta_{1,i}\ln(T_{t-i}) + \delta_{2,i}\ln(Vol_{t-i}) + \delta_{3,i}\,Spread_{t-i}.$$

r_t is the quote change after the trade t, x_t^0 is the trade indicator (1for a buy; -1 for a sell). T_t is the time between two consecutive transactions (+ 1second). *Vol* is the number of futures contracts traded. *Spread* is the difference between the last ask and the last bid price. For simplicity we present the general model above, however for the model that we used to obtain the above results we considered only the significant diurnal dummy variables. The sample covers the period from the 4 January 2000 to 30 June 2000. We used Newey-West adjustment that is consistent in the presence of both heteroskedasticity and autocorrelation of unknown form to compute *t*-statistics. Bold format denotes significance at the 5 percent level.

Time Duration			Volume			Spread		
$H_0: \delta_{1,i}$ jointly zero	$\sum \delta_{1,i}$	$H_0: \sum \delta_{1,i} = 0$	$H_0: \delta_{2,i}$ jointly zero	$\sum \delta_{2,i}$	$H_0: \sum \delta_{2,i} = 0$	$H_0: \delta_{3,i}$ jointly zero	$\sum \delta_{3,i}$	$H_0: \sum \delta_{3,i} = 0$
$\Pr ob > \chi^2$		$\Pr ob > \chi^2$	$\Pr ob > \chi^2$		$\Pr ob > \chi^2$	$\Pr ob > \chi^2$		$\Pr ob > \chi^2$
0.0000	**-0.0004**	**0.0000**	**0.0000**	**0.0008**	**0.0000**	**0.0003**	**0.0006**	**0.0362**

Table 4.9: Significance of Time in the Presence of Volume and Spread for the Quote Revision Equation

The coefficients of the trade equation

$$r_t = \sum_{i=1}^{5} a_i r_{t-i} + \sum_{i=0}^{5}\sum_{j=1}^{15} \lambda_{j,i}^{x} D_{j,t-i} x_{t-i}^{0} + \sum_{i=0}^{5} b_i x_{t-i}^{0} + v_{1,t},$$

where b_i is the parameterised as

$$b_i = \gamma_i + \delta_{1,i} \ln(T_{t-i}) + \delta_{2,i} \ln(Vol_{t-i}) + \delta_{3,i}\, Spread_{t-i}.$$

r_t is the quote change after the trade t, x_t^0 is the trade indicator (1 for a buy; -1 for a sell). T_t is the time between two consecutive transactions (+1 second). *Vol* is the number of futures contracts traded. *Spread* is the difference between the last ask and the last bid price. For simplicity we present the general model above, however for the model that we used to obtain the above results we considered only the significant diurnal dummy variables. The sample covers the period from the 4 January 2000 to 30 June 2000. We used Newey-West adjustment that is consistent in the presence of both heteroskedasticity and autocorrelation of unknown form to compute Wald statistics. We consider each group of coefficients and test the null hypothesis that these δ_i coefficients are jointly zero. We also compute the sum of these coefficients and then test the null hypothesis that this sum equals zero. The tail probabilities for the Wald statistics are computed. Bold format denotes significance at the 5 percent level.

4.5 Summary and Conclusions

In this chapter we examined the price formation process of the FTSE 100 futures contract traded on LIFFE between 4 January 2000 and 30 June 2000. In contrast with most previous studies, we considered a market where there is no market maker, and limit order traders provide liquidity. In an attempt to draw some useful conclusions on price formation in an order-driven market, we generalised the model suggested by Hasbrouck (1991) for the dynamics of trades and quote revisions. In a similar manner to Dufour and Engle (2000) we included time-of-day patterns and trade durations among the determinants of both the price impact and the autocorrelation of trades. By examining the dynamics of price formation and in particular the role of time upon price formation in an order driven market we have uncovered some similarities and differences in the dynamics of price formation in quote and order driven markets.

Our results indicate that in contrast to Dufour and Engle (2000) time-of-day effects seem to matter. Although these appear more important in the quote revision equation, with 11 out of the 14 diurnal dummies showing as significant at the current lag, and in particular among the significant diurnal dummies were the UK open and close, the US open as well as UK and US announcement effects. For the trade equation both UK announcements and the market close are significant at the first leading lag. This concurs with previous studies of UK futures markets

In consensus with Dufour and Engle (2000) we found that short trade durations, hence high trading activity are related to larger quote revisions. Further we found signed trades to exhibit strong positive autocorrelation and a buy order leads to an upward quote revision. These findings are consistent with Hasbrouck (1991) and Dufour and Engle (2000). Although we reported positive autocorrelation in returns, which is indicative of a high level of continuations, we explained such continuations are the consequence of the declining trend in prices observed over our sample period. Finally we indicated that when quotes are revised in an upward fashion, more buyers enter the market and similarly when quotes are revised in a downward fashion, more sellers enter the market. Although this is in contrast with Hasbrouck (1991) and Dufour and Engle (2000), they indicated that the negative coefficients found in the quote revisions of the sign equation were the consequence of inventory measure effects. However such market characteristics are not present in an order-driven market, where there is no market maker but only limit order traders.

In a similar manner to Dufour and Engle (2000) we performed robustness checks on trade durations and found that trade durations appeared robust for both equations in the presence of both volume and spread. However we also found these additional variables appeared to exhibit a positive and significant long-run effect on the price impact and the autocorrelations of trades. This result contrasts with Dufour and Engle (2000), who found durations to be mainly insignificant when volume and spread are included.

We conclude that price formation depends upon both trade durations and time-of-day patterns, the sign and size of a trade, the market environment as measured by the bid-ask spread and current and past levels of prices. Thus in contrast with Dufour and Engle (2000) our results indicate that time-of-day patterns and trade durations are extremely informative variables in price formation in the order driven market examined in this study.

Chapter Five

Autoregressive Conditional Duration Processes: Introducing Trade Sign Information to an Asymmetric Log-ACD Model

5.1 Introduction

In the previous chapter we provided strong empirical evidence of the relevance of time in the process of price adjustment to information in an order driven market. It follows that the time between two consecutive transactions conveys meaningful information, and has recently become the object of modelling. However to measure and forecast the intensity of the arrival of trades requires a model that can account for the irregular spacing characteristic of transaction arrivals. Traditional econometric techniques, being based on a fixed time interval analysis, does not account for this irregular spacing characteristic.

However recently Engle and Russell (1998) proposed a new econometric model for the analysis of data that does not arrive in equal time intervals, such as financial transactions. This proposed model, known as the Autoregressive Conditional Duration (ACD) model, models the time intervals directly and is therefore in the spirit of the models of time deformation initially proposed by Tauchen and Pitts (1983), Clark (1973), Stock (1988), Muller et al. (1990) and Ghysels and Jasiak (1994) but does not require auxiliary data or assumptions on the causes of time flow.

Engle and Russell (1998) proposed to let the interval between transactions be a random variable. Thus the data set comprises a list of durations and characteristics of each transaction. That is, there is a probability of a transaction arriving in each instant of time and this probability varies according to the type of transaction, the length of time since the previous transaction and any other outside influences.

One motivation behind the ACD model is the frequently observed clustering characteristic of inter-trade arrival times, typically found in high frequency financial data, (for example exchange rate trades (Engle and Russell (1997), stock market trades (Engle and Russell (1998)). This clustering characteristic is clearly indicated if the standard deviation of the series is greater than the mean.

Following the contribution of Engle and Russell (1998), several high frequency duration models have been put forward, with a motivation towards increased flexibility and generality. Bauwens and Giot (2000) introduced a logarithmic version of the ACD model, called the Log-ACD model, which is more convenient than the ACD model when conditioning variables are included in the model to test for market microstructure effects. The reason is that the ACD model practically requires the imposing of non-negativity constraints on its parameters, whereas the Log-ACD model does not. As an alternative to the Weibull distribution used in the original ACD model, Grammig and Maurer (2000) use the Burr distribution, and Lunde (1999) uses the generalised gamma distribution (both of these distributions include the Weibull as a particular case). Ghysels, Gouriéroux and Jasiak (1997) proposed the stochastic volatility duration model, which accounts for stochastic volatility in the durations. Bauwens and Veredas (2003) introduced the stochastic conditional duration (SCD) model, which uses a stochastic volatility type model instead of a GARCH-type model, to model the durations. Jasiak (1999) introduced the Fractional Integrated ACD (FIACD) process to allow for the characteristic of long-term memory effects.

However an important feature prevalent in all these models above is that although they account for the duration between market events and they include additional variables drawn from the market microstructure literature such as volume and spread, they do not include information about the trade sign process. This may be an important drawback, as both the earlier results of Dufour and Engle (2000) and the previous chapter indicate that the trade sign is closely related to the time between transactions. Thus combining information given by the trade sign process and the duration between transactions seems a natural extension. Further, in contrast to Dufour and Engle (2000) we found trade durations to be robust in the presence of both volume and spread. Although not conclusive, we suggested that time maybe a more informative variable in an order driven market compared with a quote driven market. Hence by modelling the trade intensity process and in particular the impact of the sign of the previous transaction upon trading intensity, we illuminate this process in an order driven market. This provides a comparative analysis of the trade intensity process in an order driven market to a quote driven market.

This chapter uses an Autoregressive Conditional Duration (ACD) framework, as proposed by Engle and Russell (1998) to model the transaction process of the FTSE 100 futures contract between 4 January 2000 and 30 June 2000. First, we follow a similar methodology to Engle and Russell (1998) to provide a comparative analysis of both the exponential and the Weibull versions of the ACD model. Second, by incorporating trade sign, we extend the asymmetric Log-ACD model first proposed by Bauwens and Giot (2003). The asymmetry in the model proposed in this study comes from the dependency of the duration process on trade sign. If a buyer initiates a trade the duration process may differ compared to when a seller initiates a trade. Additionally, in order to better specify the expected conditional duration, we include trading volume and spread into our version of the asymmetric Log-ACD model.

The rest of this chapter is organised as follows. In Section 5.2 we review the ACD model of Engle and Russell (1998). In Section 5.3 we describe the nature of the durations for the FTSE 100 futures contract. In Section 5.4 we present the estimation results of both the EACD and the WACD models. In Section 5.5 we review the Log-ACD model of Bauwens and Giot (2000). In Section 5.6 we extend the asymmetric Log-ACD model of Bauwens and Giot (2003) to examine the existence of an asymmetric trade sign effect upon the trade intensity process. We also include volume and spread as additional explanatory variables.

5.2 Review of the ACD Model

5.2.1 The ACD Model

The ACD model first introduced by Engle and Russell (1998) shares some features of the GARCH model. Instead of modelling an autoregressive process on the variance of the returns as in the GARCH model, the ACD model bears on the autoregressive structure displayed by durations. This model is particularly well suited to the analysis of irregularly spaced data, where the time elapsed between two trades conveys meaningful information.

Let x_i be the duration between two consecutive transactions occurring at times t_i and t_{i-1} i.e. $x_i = t_i - t_{i-1}$, which is measured in seconds. The assumption introduced by Engle and Russell (1998) is that the time dependence in the durations can be subsumed in their conditional expectations $\Psi_i = E(x_i \mid F_{i-1})$ in such a way that x_i / Ψ_i is independent and identically distributed. F_{i-1} denotes the information set available at time t_{i-1}, (i.e. at the beginning of duration x_i), and contains at least x_{i-1} and its past values and Ψ_{i-1} and its past values.

The ACD model specifies the observed duration as a mixing process:

$$x_i = \Phi_i \varepsilon_i, \tag{5.1}$$

where the ε_i are independent and identically distributed and follow a Weibull $(1,\gamma)$ probability distribution, while the Φ_i are proportional to the conditional expectation of x_i as explained below.

A second equation specifies an autoregressive model for the (expected) conditional durations[1]:

$$\Psi_i = \omega + \alpha_1 x_{i-1} + \alpha_2 x_{i-2} + \ldots + \alpha_m x_{i-m} + \beta_1 \Psi_{i-1} + \beta_2 \Psi_{i-2} + \ldots + \beta_q \Psi_{i-q}, \qquad (5.2)$$

with the following constraints on the coefficients: $\omega > 0, \alpha_i \geq 0, \beta_i \geq 0$ and $\sum_{i=1}^{\max\{m,q\}} (\alpha_i + \beta_i) < 1$. The last constraint ensures the existence of the unconditional mean of the duration, while the others simply ensure the positivity of the conditional durations.

The condition $\Psi_i = E(x_i \mid F_{i-1})$ provides us with a third equation, linking equations (5.1) and (5.2):

$$\Psi_i = \Gamma\left(1 + \frac{1}{\gamma}\right)\Phi_i, \qquad (5.3)$$

where $\Gamma(.)$ is the gamma function. The exponential distribution is obtained as a special case of the Weibull distribution when $\gamma = 1$. In which case, $\Phi_i = \Psi_i$.

The autoregressive structure of the conditional expectations of the durations implies that small durations are more likely to be followed by small durations (and likewise for long durations). Thus the model accounts for the clustering effect of durations. The Weibull distribution is preferred over the exponential. While the exponential is a very tractable model specification, it is also very inflexible. The single parameter in the distribution

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[1] This model is the ACD (m,q) model.

yields the well-known property of a constant proportional hazard. However the probability of a trade at time t conditioned on no trade up to time t may not be constant. However for the Weibull distribution, the conditional intensity is a two-parameter family, which can exhibit either increasing or decreasing hazard functions. This makes especially long durations more or less likely than for the exponential depending on whether γ is less or greater than unity respectively.

5.2.2 Statistical Properties of the ACD Model

By definition, the conditional expectation of x_i is equal to Ψ_i. Similarly the conditional variance of x_i is Ψ_i^2. Thus equation (5.2) provides a way to forecast expected durations, based on the information available at the previous durations. The constant unconditional expectation (μ) and variance (σ^2) of x_i are given by

$$\mu = E(x_i) = \frac{\omega}{1 - \sum_{i=1}^{\max\{m,q\}} (\alpha_i + \beta_i)} \tag{5.4}$$

and

$$\sigma^2 = \mu^2 k \frac{1 - 2\alpha\beta - \beta^2}{1 - (\alpha + \beta)^2 - \alpha^2 k} \tag{5.5}$$

The result shows that the unconditional standard deviation exceeds the mean whenever $\alpha > 0$, and is therefore consistent with the excess dispersion that is typically observed in duration data. For the exponential model $k = 1$ so there is no excess dispersion in the standard deviations even though there is in the unconditional durations.

For the Weibull with parameter γ, it can be shown that

$$k = \left\{ \frac{\Gamma\left(1+\frac{2}{\gamma}\right)}{\Gamma\left(1+\frac{1}{\gamma}\right)^{2}} - 1 \right\} \tag{5.6}$$

Similar but increasingly complicated results can be obtained for the higher moments and for the higher order models. For a proof of these results see, Engle and Russell (1998).

5.2.3 The Likelihood Function of an ACD Model

By definition the exponential density function of x_i can be written as

$$f(x_i) = \frac{1}{x_i}\left(\frac{x_i}{\Psi_i}\right) e^{-\left(\frac{x_i}{\Psi_i}\right)}, \tag{5.7}$$

Using equation (5.7), we can write the log-likelihood function of the observation $x_i, i = 1,\ldots,N$ as

$$-\sum_{i=1}^{N}\left[\ln(\Psi_i) + \frac{x_i}{\Psi_i}\right], \tag{5.8}$$

with Ψ_i defined by equation (5.2).

By definition the Weibull density function of x_i can be written as

$$f(x_i) = \frac{\gamma}{x_i}\left(\frac{x_i\Gamma\left(1+\frac{1}{\gamma}\right)}{\Psi_i}\right)^{\gamma} e^{-\left(\frac{x_i\Gamma\left(1+\frac{1}{\gamma}\right)}{\Psi_i}\right)^{\gamma}}, \tag{5.9}$$

Using equation (5.9) we can write the log-likelihood function of the observation x_i, $i = 1,\ldots,N$ as

$$\ln(\gamma) - \sum_{i=1}^{N}\ln(x_i) + \gamma \ln\left[x_i\Gamma\left(1+\frac{1}{\gamma}\right)\right] - \gamma \ln(\Psi_i) - \left(\frac{x_i\Gamma\left(1+\frac{1}{\gamma}\right)}{\Psi_i}\right)^{\gamma}, \tag{5.10}$$

with Ψ_i defined by equation (5.2).

5.3 The Durations

5.3.1 Descriptive Statistics

After all the adjustments to the data (see section 4.2.2), there are 804,555 observations on FTSE 100 transactions to be analysed. The data sample covers the period from 4 January 2000 to 30 June 2000. The average time interval between transactions is 5.37 seconds, the minimum interval is 0 seconds and the maximum interval is 479 seconds. The standard deviation is 8.75 seconds and the skewness is 6.59. A histogram of these durations is shown in Figure 5.1. For a Poisson process the means should be equal to the standard deviation, our data set clearly exhibits excess variance in durations.

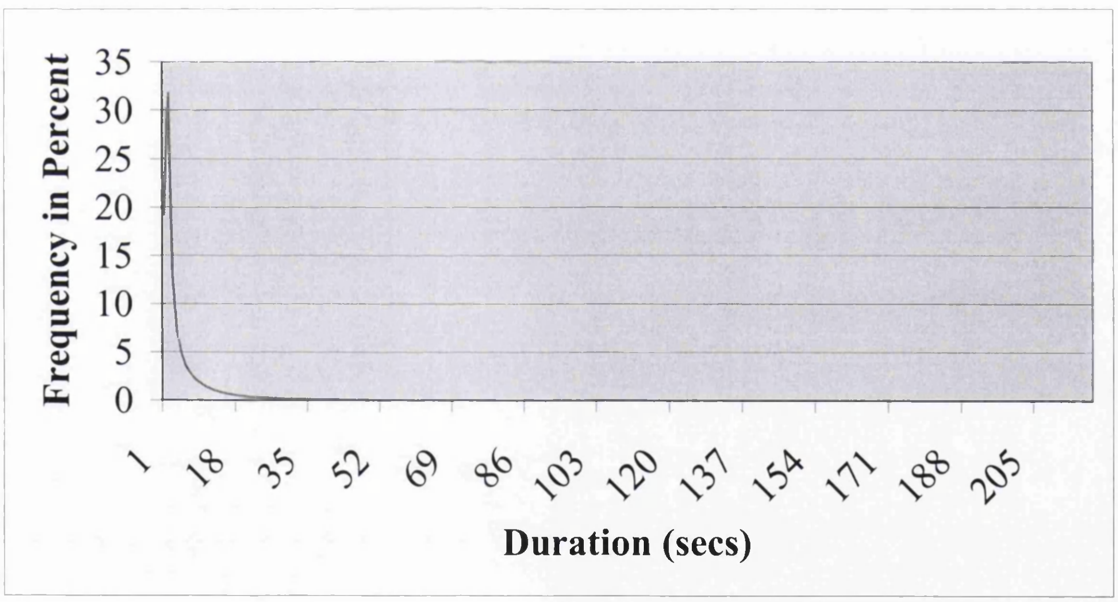

Figure 5.1: Duration Histogram

5.3.2 Time-of-Day Effects

Figure 5.2 presents mean durations for different periods over the trading day. The data exhibits the well-known property of high activity (small durations) in the morning and just prior to close. Durations are longest in the middle of the day. The mean duration is 1.5 times higher during lunchtime than that at the opening, with the average trade duration around 13:00 being 8.72 seconds and the average duration around the opening being 4.66 seconds. The durations are twice as high during lunchtime compared with just prior to the market close, where the average duration is 3.24 seconds. An additional time of high activity hence lower trade durations was observed around the US open, with an average duration of 4.34 seconds. In Table 5.1 we present the descriptive statistics for our durations conditioned on the time of day.

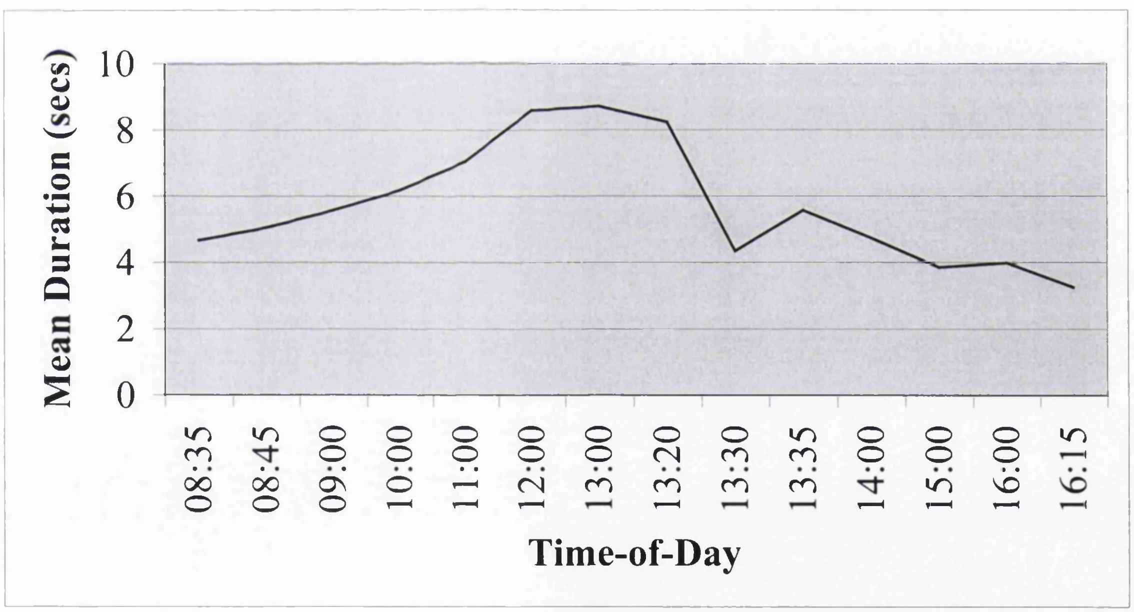

Figure 5.2: Mean Duration Conditioned on the Time of Day

Time-of-day	Frequency	Mean	Standard Deviation
08:35:00 - 08:44:59	18815	4.662	6.220
08:45:00 – 08:59:59	27519	5.045	6.765
09:00:00 – 09:59:59	96411	5.568	8.123
10:00:00 – 10:59:59	85750	6.169	9.501
11:00:00 – 11:59:59	73729	7.039	11.537
12:00:00 – 12:59:59	58696	8.591	14.348
13:00:00 – 13:19:59	20871	8.716	14.633
13:20:00 – 13:29:59	10730	8.232	12.816
13:30:00 – 13:34:59	11743	4.341	7.596
13:35:00 – 13:59:59	39401	5.561	8.956
14:00:00 – 14:59:59	116899	4.736	7.534
15:00:00 – 15:59:59	156964	3.842	4.689
16:00:00 – 16:14:59	37459	3.976	4.889
16:15:00 – 16:29:59	49568	3.241	3.684

Table 5.1: Descriptive statistics for the durations

5.3.3 Autocorrelations and Partial Autocorrelations

The ACD model is proposed as a model for intertemporally correlated event arrival times. To examine the dependence, we calculate the autocorrelations and the partial autocorrelations of the durations, or the waiting times between consecutive transactions. Table 5.2 shows these autocorrelations with the overnight waiting times removed. The autocorrelations and partial autocorrelations are far from zero and all the signs are positive. The Ljung-Box statistic is examined to formally test the null hypothesis that the first 15 autocorrelations are zero. The test statistic is distributed as a χ^2_{15} with a 5% critical value of 24.99. The null is very easily rejected with a chi-squared statistic of 207697 and a corresponding p-value of 0.000. These long autocorrelations are exactly what is found for autocorrelations of squared returns. Engle and Russell (1998) show that volatility clustering and trade duration clustering exhibit many similarities.

We remove the deterministic diurnal component Δ_j where Δ_j represents the mean duration of the time-of-day interval containing x_i and consider the diurnally adjusted series of time durations

$$\widetilde{x}_i = \frac{x_i}{\Delta_j} \tag{5.11}$$

The new diurnally adjusted series $\widetilde{x}_i$ has a mean of 1, a standard deviation of 1.46 and should be free of any daily periodicity. The autocorrelations and partial autocorrelations of the diurnally adjusted durations are also shown in Table 5.2. The new Ljung-Box statistic for the first 15 lags associated with the diurnally adjusted series is 125078. This indicates that dependency between durations still exists after the removal of the diurnal effects.

Lag	Raw Durations			Diurnally Adjusted Durations		
	ACF	PACF	Q-stat	ACF	PACF	Q-stat
1	0.188	0.188	28528	0.160	0.160	20488
2	0.156	0.125	48113	0.125	0.102	33041
3	0.144	0.100	64771	0.113	0.082	43376
4	0.136	0.083	79660	0.106	0.069	52439
5	0.131	0.072	93399	0.101	0.061	60713
6	0.126	0.063	106139	0.096	0.053	68172
7	0.128	0.062	119241	0.097	0.052	75811
8	0.125	0.056	131788	0.094	0.046	82967
9	0.120	0.048	143341	0.090	0.041	89508
10	0.120	0.047	154978	0.091	0.040	96123
11	0.118	0.043	166211	0.087	0.035	102255
12	0.113	0.036	176437	0.084	0.031	107923
13	0.114	0.037	186900	0.084	0.032	113648
14	0.113	0.035	197159	0.084	0.030	119270
15	0.114	0.036	207697	0.085	0.031	125078

Table 5.2: Autocorrelations and Partial Autocorrelations of Trading Interval.

5.4 Estimation of the ACD Models

The ACD model consists first of a distributional assumption for the conditional density of the adjusted durations $\tilde{x}_i$. In the ACD model first proposed by Engle and Russell (1998), the Weibull distribution is preferred to the exponential distribution. They found the restrictive constant proportional hazard to be inappropriate. It follows, that in a similar manner to Engle and Russell (1998) we empirically test whether the Weibull version of the ACD model is preferred to the exponential version of the ACD model for the FTSE 100 durations considered in this chapter.

We proceed by maximising the log-likelihood functions for the exponential and Weibull versions of the ACD models as described in section 5.2.1. To perform maximum likelihood estimation, we used the Marquadt algorithm in Eviews 4.1. The algorithm has no trouble in converging for these samples and the results are robust to the choice of starting values. To allow for inter-day effects a dummy variable was included taking a value of 1 if it is the first observation of the day and zero elsewhere.

5.4.1 The Exponential ACD (EACD) Models

The parameter estimates for both the EACD (2,1) model and the EACD (2,2) model are presented in Table 5.3. Our results indicate that all the included variables are significant at the 1% level. In contrast to Engle and Russell (1998), we did not find reduced *t*-statistics for the EACD (2,2) model, which they attribute to multicollinearity. The results shown in table 5.3 indicate that this is not a problem in our model. For a constant unconditional mean to exist, the sum of α_i's and β_i's must be less than one. Both models are close to being integrated with the sum of α_i's and β_i's equal to 0.993 and 0.997 for the EACD (2,1) model and the EACD (2,2) model respectively. This indicates that the process has strong persistence as measured in transaction time. The implied unconditional means are 1.051 and 1.071 for the EACD (2,1) and the EACD (2,2) models respectively.

The ACD process assumes that a particular stochastic transformation of the data is independent and identically distributed. Testing this assumption provides a diagnostic test of the model.

The 'standardised' durations series

$$\varepsilon_i = \frac{\tilde{x}_i}{\Psi_i}, \tag{5.12}$$

are tested for autocorrelation using the Ljung Box statistic with 15 lags. The Ljung-Box statistics are 455.94 and 160.15 for the EACD (2,1) model and the EACD (2,2) model respectively. Both of these values are much less than those computed for the raw and diurnally adjusted durations, however these values are still greater than the critical value (24.99 at the 5% level), and the null hypothesis of white noise is rejected for both models. The independence assumption in equation (5.1) implies that higher order moments should also be independent. The Ljung-Box statistic for the square of the standardised series is 110.16 and 143.30 for the EACD (2,1) model and the EACD (2,2) model respectively. Higher order moments are also greater than the critical value. These statistics suggest that the model does not do a good job of accounting for the intertemporal dependence in transaction rates, and that the large Ljung-Box statistic observed for the raw durations in Table 5.2 is not a result of the daily factor alone. This observation is supported by the large *t*-statistics observed for the parameters α_i and β_i which are designed to capture this inter-temporal autocorrelation.

One goodness of fit test is a simple moment condition implied by the exponential distribution. In particular the exponential distribution implies that the mean should equal the standard deviation. The mean of the standardised durations is unity by first order conditions while the standard deviations are 1.222 and 1.218 for the EACD (2,1) model and the EACD (2,2) model respectively.

A simple test of the null of no excess dispersion is then based on the statistic $\sqrt{N}\left(\left(\hat{\sigma}_\varepsilon^2 - 1\right)/\sigma_v\right)$ where $\hat{\sigma}_\varepsilon^2$ is the sample variance of $\hat{\varepsilon}$, which should be 1 under the null hypothesis. σ_v is the standard deviation of $(\varepsilon_i - 1)^2$ which is equal to $\sqrt{8}$ under the exponential null hypothesis. A straightforward application of a central limit theorem implies this statistic should have a limiting normal distribution under the null with a 5% critical value of 1.96. The null of the standard deviation equal to unity is easily accepted with *t*-statistics of 0.936 and 0.941 for the EACD (2,1) and the EACD (2,2) model respectively.

	EACD (2,1)			**EACD (2,2)**		
	Coefficient	**Std. Error**	**T-Statistic**	**Coefficient**	**Std. Error**	**T-Statistic**
ω	0.007	0.000	52.065	0.003	0.000	47.644
α_1	0.130	0.001	115.323	0.125	0.001	134.684
α_2	-0.086	0.001	-75.775	-0.106	0.001	-112.316
β_1	0.950	0.000	2622.195	1.423	0.000	4727.944
β_2	-	-	-	-0.444	0.000	-1076.575
λ	0.279	0.024	11.754	0.133	0.011	11.542

Table 5.3: Maximum Likelihood Estimates of EACD Models after Removing Time of Day Effects

We estimate the Exponential Autoregressive Conditional Duration (EACD) models on FTSE 100 intertrade durations (+1 second) after removing the time-of-day effect. We use duration data for the period from 4 January 2000 to 30 June 2000. We remove the deterministic diurnal component Δ_j where Δ_j represents the mean duration of the time-of-day interval containing x_i and consider the diurnally adjusted series of time durations $\tilde{x}_i = x_i / \Delta_j$.

Assuming that $\tilde{x}_i$ has an exponential distribution, the estimated EACD models are

$$\Psi_i = \omega + \alpha_1 \tilde{x}_{i-1} + \alpha_2 \tilde{x}_{i-2} + \beta_1 \Psi_{i-1} + \beta_2 \Psi_{i-2} + \lambda D_{i-1},$$

and

$$f(x_i) = \frac{1}{x_i}\left(\frac{x_i}{\Psi_i}\right) e^{-\left(\frac{x_i}{\Psi_i}\right)}, \qquad \text{for } \Psi_i > 0.$$

D_i is a dummy variable for the first observation of the trading day.

5.4.2 The Weibull ACD (WACD) Models

The parameter estimates for the WACD (2,1) model and the WACD (2,2) model are presented in Table 5.4. Our results indicate that all the included variables are significant at the 1% level. The parameter estimates of γ are 1.06 for both the WACD (2,1) and the WACD (2,2) models respectively. The exponential model is easily rejected in favour of the Weibull with a t statistic associated with a null hypothesis of $\gamma=1$ of 57 and 64 for the WACD (2,1) model and the WACD (2,2) model respectively. For a constant unconditional mean to exist, requires the sum of α_i's and β_i's to be less than one. Both models are close to being integrated with the sum of α_i's and β_i's equal to 0.994 and 0.997 for the WACD (2,1) model and the WACD (2,2) model respectively. The implied unconditional means are 1.112 and 1.205 for the WACD (2,1) model and the WACD (2,2) model respectively. Given the similarities in the parameters, it is not surprising to find that the standardised series exhibit similar autocovariances and Ljung-Box statistics. If the Weibull specification is correct then raising the residuals to the power γ should produce a series that remains independent and identically distributed, and is also distributed as a unit exponential. By applying the same set of diagnostic tests as before to the transformed Weibull 'standardised' series,

$$\varepsilon_i = \left(\frac{\tilde{x}_i}{\Psi_i} \right)^{\gamma}, \tag{5.13}$$

yields associated Ljung-Box statistics are 428.13 and 145.85 for the WACD (2,1) model and the WACD (2,2) model respectively. Again these are a great improvement over the Ljung-Box statistics associated with the raw and diurnally adjusted durations, and although slightly less, these values remain very similar to those computed for the EACD models. The Ljung-Box statistic for the square of the standardised series is 77.57 and 105.83 for the WACD (2,1) model and the WACD (2,2) model respectively. These statistics suggest that the model does not account for all of the intertemporal dependence in transaction rates.

The standard deviations of ε_i are 1.325 and 1.327 for the WACD (2,1) model and the WACD (2,2) model respectively. The test for excess dispersion of the transformed series yields t-statistic of 1.377 and 1.383 for the WACD (2,1) and the WACD (2,2) model respectively. Therefore, we accept the null of no excess dispersion.

	WACD (2,1)			WACD (2,2)		
	Coefficient	**Std. Error**	**T-Statistic**	**Coefficient**	**Std. Error**	**T-Statistic**
ω	0.006	0.000	56.229	0.003	0.000	62.190
α_1	0.130	0.001	130.720	0.128	0.001	147.948
α_2	-0.086	0.001	-85.466	-0.104	0.001	-120.663
β_1	0.950	0.000	3057.098	1.326	0.000	731331.100
β_2	-	-	-	-0.353	0.000	-3767.868
γ	1.057	0.001	1273.710	1.064	0.001	1288.113
λ	0.284	0.020	13.621	0.170	0.012	13.784

Table 5.4: Maximum Likelihood Estimates of WACD Models after Removing Time of Day Effects

We estimate the Weibull Autoregressive Conditional Duration (WACD) models on FTSE 100 intertrade durations (+1 second) after removing the time-of-day effect. We use duration data for the period from 4 January 2000 to 30 June 2000. We remove the deterministic diurnal component Δ_j where Δ_j represents the mean duration of the time-of-day interval containing x_i and consider the diurnally adjusted series of time durations $\tilde{x}_i = x_i/\Delta_j$.

Assuming that $\tilde{x}_i$ has a Weibull distribution, the estimated WACD models are

$$\Psi_i = \omega + \alpha_1 \tilde{x}_{i-1} + \alpha_2 \tilde{x}_{i-2} + \beta_1 \Psi_{i-1} + \beta_2 \Psi_{i-2} + \lambda D_{i-1},$$

and

$$f(x_i) = \frac{\gamma}{x_i}\left(\frac{x_i \Gamma\left(1+\frac{1}{\gamma}\right)}{\Psi_i}\right)^{\gamma} e^{-\left(\frac{x_i \Gamma\left(1+\frac{1}{\gamma}\right)}{\Psi_i}\right)^{\gamma}}, \qquad \text{for } \gamma, \Psi > 0.$$

D_i is a dummy variable for the first observation of the trading day.

The results of the EACD and the WACD models above suggest that although both the exponential and the Weibull versions of the ACD models account for much of the intertemporal correlation in durations, both models remained incapable of accounting for all of the dependency. For both the exponential and the Weibull versions of the ACD models we were able to accept the null of no excess dispersion. However the finding of $\gamma = 1.06$ for both of the WACD models, indicates that especially long durations are less likely in our FTSE 100 durations data. Further, the null of $\gamma = 1$ is strongly rejected; this indicates that we prefer the Weibull to the exponential. Thus in a similar manner to Engle and Russsell (1998), we suggest that the constant proportional hazard feature of the exponential function is inappropriate for our durations data.

The duration models above are self-contained, in that the durations are modelled conditionally on the past durations. Microstructure effects relating to durations were not considered in the models above. Such effects may include trading volume, transaction price, bid-ask spread and volatility. The importance of including such variables within the ACD framework was first proposed by Engle and Russell (1998) and has more recently become the motivation for the development of new models. The necessity for this development is due to the restrictive positivity constraints imposed upon the coefficients of the ACD model, which becomes a problem if we wish to include additional explanatory variables to test for market microstructure effects.

Following this argument Bauwens and Giot (2000) proposed the Log-ACD model; a variant to the ACD model that does not require positivity of the coefficients. In the next section we briefly review the Log-ACD model of Bauwens and Giot (2000). Although we do not consider market microstructure effects in the basic Log-ACD model outlined below, it provides us with a framework for building a new model, which we introduce in Section 5.6. This new model combines information on the duration and direction of the trade sign. For these reasons we believe that a brief discussion of the underlying Log-ACD model is needed before we introduce our new model.

5.5 The Log-ACD Model

As in the ACD model, let x_i be the duration between two consecutive trades. The logarithmic version of the ACD model changes the mixing process of equation (5.1) of the ACD model into the following equation:

$$x_i = e^{\phi_i}\varepsilon_i \tag{5.14}$$

where the ε_i are independent and identically distributed and follow a Weibull $(1,\gamma)$ distribution, while ϕ_i is proportional to the logarithm of the conditional expectation of x_i as explained below.

Let ψ_i be the logarithm of the conditional expectation of x_i so that $\psi_i = \ln E(x_i|F_{i-1})$. A second equation specifies an autoregressive model for the logarithm of the conditional durations:

$$\psi_i = \omega + \alpha\, g(x_{i-1}, \varepsilon_{i-1}) + \beta\psi_{i-1}, \tag{5.15}$$

For positivity of e^{ψ_i} and thus of x_i, there are no restrictions on the signs of the parameters ω, α and β.

The condition $\psi_i = \ln E(x_i|F_{i-1})$ or $e^{\psi_i} = E(x_i|F_{i-1})$ provides an equation, linking equations (5.14) and (5.15):

$$e^{\phi_i}\Gamma\left(1+\frac{1}{\gamma}\right) = e^{\psi_i} \tag{5.16}$$

Although Bauwens and Giot (2000) proposed several choices for $g(x_{i-1}, \varepsilon_{i-1})$, we consider,

$$\psi_i = \omega + \alpha \frac{x_{i-1}\Gamma(1+1/\gamma)}{e^{\psi_{i-1}}} + \beta\psi_{i-1}, \tag{5.17}$$

In this specification the logarithm of the conditional expectation depends on its past lagged value and on the lagged 'excess duration'. This model is close to the exponential GARCH model of Nelson (1991). For covariance stationarity of ψ_i,$|\beta|$ must be smaller than one.

By definition of the Weibull density, the density function of x_i can be written as

$$f(x_i) = \frac{\gamma}{x_i}\left(\frac{x_i\Gamma\left(1+\frac{1}{\gamma}\right)}{e^{\psi_i}}\right)^{\gamma} e^{-\left(\frac{x_i\Gamma\left(1+\frac{1}{\gamma}\right)}{e^{\psi_i}}\right)^{\gamma}}, \tag{5.18}$$

Using (5.18) we can write the log-likelihood equation of the observations x_i, $i = 1,\ldots,N$ as

$$\ln(\gamma) - \sum_{i=1}^{N}\ln(x_i) + \gamma\ln[x_i\Gamma(1+1/\gamma)] - \gamma\psi_i - \left(\frac{x_i\Gamma(1+1/\gamma)}{e^{\psi_i}}\right)^{\gamma} \tag{5.19}$$

Using the Log-ACD model of Bauwens and Giot (2000) outlined above, we wish to extend this model to incorporate asymmetric effects similar to the one proposed by Bauwens and Giot (2003). In Bauwens and Giot (2003) they considered letting the bid-ask quote duration process depend on the state of the price process. However in the model developed here, we let the transaction duration process depend on the state of the trade sign process.

As a further extension we follow suggestions made by many authors of including additional explanatory variables drawn from the market microstructure literature in order to better specify the expected conditional duration. In this model we consider both trade volume and spread. It is proposed here that a moving average of the past realisations of volume and spread provides more information about the current state of the market than a single past realisation. We therefore construct a moving average of volume and spread using 10 equally weighted lags. Ten transactions correspond on average, to around 55 seconds of trading. Just as the durations exhibit a deterministic component, it is a stylised fact that both volume and spread exhibit a similar deterministic component (see section 4.1). We therefore removed the time-of-day effects in a similar manner as we did for the durations.

5.6 An Asymmetric Log-ACD Model

In our framework we consider a marked point process consisting of the pairs (x_i, y_i), where x_i is as before the duration between two trades, and y_i is a variable indicating the sign of trade x_i such that:

$y_i = 1$ if a buyer initiated trade x_i;

$y_i = -1$ if a seller initiated trade x_i;

such that

$$I_i^+ \begin{cases} =1 \text{ if } y_{i=1} = 1 \\ =0 \text{ if } y_{i=1} = -1 \end{cases} \tag{5.20}$$

and

$$I_I^- = 1 - I_I^+ \tag{5.21}$$

At the end of duration x_i there are only two possible end states either where $y_i = 1$ or $y_i = -1$. We assume a hazard function of the Weibull ACD type, i.e. we let the hazard depend not only on the previous state but also on the previous durations.

Combining a two-state competing risk model with a Log-ACD model yields an asymmetric Log-ACD model, which is defined by the following equations:

If the end state of duration x_i is $y_i = 1$, the hazard for x_i, assuming a Weibull distribution, is given by

$$h(x_i|y_i = 1, F_{i-1}) = \frac{\gamma^+}{x_i}\left(\frac{x_i\Gamma(1+1/\gamma^+)}{e^{\psi_i^+}}\right)^{\gamma^+} \tag{5.22}$$

with $e^{\psi_i^+} = \Psi_i^+$, and the autoregressive process ψ_i^+ is defined as

$$\begin{aligned}\psi_i^+ = &\left(\omega_1 + \alpha_1 \frac{x_{i-1}\Gamma(1+1/\gamma^+)}{e^{\psi_{i-1}^+}}\right) I_{i-1}^+ + \left(\omega_2 + \alpha_2 \frac{x_{i-1}\Gamma(1+1/\gamma^+)}{e^{\psi_{i-1}^+}}\right) I_{i-1}^- + \\ &\beta^+\psi_{i-1}^+ + \delta_1^+ NewDay_{i-1} + \delta_2^+ Vol_{i-1} + \delta_3^+ Spread_{i-1}\end{aligned} \tag{5.23}$$

with

$$x_i = e^{\phi_i^+}\varepsilon_i^+ \tag{5.24}$$

The condition $\psi_i^+ = \ln E(x_i|F_{i-1})$ or $e^{\psi_i^+} = E(x_i|F_{i-1})$ provides an equation, linking equations (5.23) and (5.24):

$$e^{\phi_i^+}\Gamma\left(1 + \frac{1}{\gamma^+}\right) = e^{\psi_i^+} \tag{5.25}$$

If the end state of duration x_i is $y_i = -1$, the hazard of x_i assuming a Weibull distribution, is given by

$$h(x_i | y_i = -1, F_{i-1}) = \frac{\gamma^-}{x_i}\left(\frac{x_i \Gamma(1 + 1/\gamma^-)}{e^{\psi_i^-}}\right)^{\gamma^-} \tag{5.26}$$

with $e^{\psi_i^-} = \Psi_i^-$, and the autoregressive process ψ_i^- is defined as

$$\begin{aligned} \psi_i^- = &\left(\omega_3 + \alpha_3 \frac{x_{i-1}\Gamma(1 + 1/\gamma^-)}{e^{\psi_{i-1}^-}}\right) I_{i-1}^+ + \left(\omega_4 + \alpha_4 \frac{x_{i-1}\Gamma(1 + 1/\gamma^-)}{e^{\psi_{i-1}^-}}\right) I_{i-1}^- + \\ &\beta^- \psi_{i-1}^- + \delta_1^- NewDay_{i-1} + \delta_2^- Vol_{i-1} + \delta_3^- Spread_{i-1} \end{aligned} \tag{5.27}$$

with

$$x_i = e^{\phi_i^-} \varepsilon_i^- \tag{5.28}$$

The condition $\psi_i^- = \ln E(x_i | F_{i-1})$ or $e^{\psi_i^-} = E(x_i | F_{i-1})$ provides an equation, linking equations (5.27) and (5.28):

$$e^{\phi_i^-} \Gamma\left(1 + \frac{1}{\gamma^-}\right) = e^{\psi_i^-} \tag{5.29}$$

At the end state of x_i either state $y_i = 1$ or $y_i = -1$ is realised. In the framework of a competing risk model, the duration corresponding to the state that is not realised is truncated, since the observed duration is the minimum of two possible durations: the one which would realise if $y_i = 1$ and the one which would realise if $y_i = -1$. The realised state contributes to the likelihood function via its density function, while the truncated state contributes to the likelihood function via its survivor function.

The joint density of duration x_i and state y_i given the past state and the past duration is given by:

$$f(x_i, y_i | F_{i-1}) = \left[\frac{\gamma^+}{x_i}\left(\frac{x_i\Gamma(1+1/\gamma^+)}{e^{\psi_i^+}}\right)^{\gamma^+}\right]^{I_i^+} e^{-\left(\frac{x_i\Gamma(1+1/\gamma^+)}{e^{\psi_i^+}}\right)^{\gamma^+}} \left[\frac{\gamma^-}{x_i}\left(\frac{x_i\Gamma(1+1/\gamma^-)}{e^{\psi_i^-}}\right)^{\gamma^-}\right]^{I_i^-} e^{-\left(\frac{x_i\Gamma(1+1/\gamma^-)}{e^{\psi_i^-}}\right)^{\gamma^-}}$$

(5.30)

Using (5.30) we can write the log likelihood of the observation $x_i, i = 1,..., N$ as

$$\ln(\gamma^+)*I_i^+ - \sum_{i=1}^{N}\ln(x_i)*I_i^+ + \gamma^+\ln\left(x_i\Gamma\left(1+\frac{1}{\gamma^+}\right)\right)*I_i^+ - \gamma^+\psi_i^+ * I_i^+ - \left(\frac{x_i\Gamma\left(1+\frac{1}{\gamma^+}\right)}{e^{\psi_i^+}}\right)^{\gamma^+} +$$

(5.31)

$$\ln(\gamma^-)*I_i^- - \sum_{i=1}^{N}\ln(x_i)*I_i^- + \gamma^-\ln\left(x_i\Gamma\left(1+\frac{1}{\gamma^-}\right)\right)*I_i^- - \gamma^-\psi_i^- * I_i^- - \left(\frac{x_i\Gamma\left(1+\frac{1}{\gamma^-}\right)}{e^{\psi_i^-}}\right)^{\gamma^-}$$

5.6.1 Empirical Results

The parameter estimates for the asymmetric Log ACD model are presented in Table 5.5. Our results indicate that all included variables are significant at the 1% level of significance. The estimation is performed by maximising the likelihood function defined in equation (5.31), using the Marquadt algorithm implemented in Eviews 4.1. The first three columns of Table 5.5 are for the part of the model, when the end state is a buyer-initiated trade (see equations (5.23) and (5.24)) and the last three columns are for the part of the model, when the end state is a seller-initiated trade (see equations (5.27) and (5.28)).

Our results indicate that as in the EACD and the WACD models, we find strong autoregressive effects (β coefficients), indicating a strong persistence in the dynamics of the duration process. In addition we note that the inclusion of volume and spread hardly changes the estimates of the β coefficients. As indicated in the WACD models, the estimates for the γ parameters exceed yet remain close to one. Furthermore, we indicate that $\gamma^+ = \gamma^-$ and $\gamma^+ = \gamma^- = 1$ are rejected at the 5% level of significance. These results confirm our earlier findings that the exponential distribution is inappropriate for our data. The estimates of δ_1^+ and δ_1^- are negative and significant which indicates, negative inter-day effects. The estimates of δ_2^+ and δ_2^- are negative and significant. This indicates, that when average volume per trade increases, the next expected duration becomes smaller. The estimates of δ_3^+ and δ_3^- are also negative and significant. This indicates, that when average spread per trade increases this decreases the next expected duration between FTSE 100 transactions.

Furthermore, the results given in Table 5.5 indicate that, for each additional variable included in the model, the corresponding coefficients for the two states (a buyer-initiated trade and a seller-initiated trade) are quite close. However we find that a test of the hypothesis that $\delta_2^+ = \delta_2^-$ is rejected at the 5% level of significance. However a test of the hypothesis that $\delta_3^+ = \delta_3^-$ cannot be rejected at the 5% level of significance. This indicates that both volume are spread play an important informational role in the trade intensity process. Furthermore when trade volume decreases the next expected duration becomes smaller. This relationship appears to be of particular importance when the end state is a buyer-initiated trade. However when spread decreases the next expected duration becomes smaller, and this relationship is similar for both end states.

	End State: Buyer Initiated				End State: Seller Initiated		
	Coefficient	Std. Error	T-Statistic		Coefficient	Std. Error	T-Statistic
ω_1	-0.121	0.001	-114.993	ω_3	0.027	0.001	22.339
ω_2	0.017	0.001	15.481	ω_4	-0.135	0.001	-124.427
α_1	0.150	0.001	113.761	α_3	0.237	0.002	138.987
α_2	0.232	0.002	134.400	α_4	0.160	0.001	122.381
β^+	0.941	0.001	1602.121	β^-	0.933	0.001	1535.253
γ^+	1.051	0.001	726.024	γ^-	1.039	0.001	732.964
δ_1^+	-0.078	0.014	-5.690	δ_1^-	-0.064	0.015	-4.411
δ_2^+	-0.004	0.000	-9.203	δ_2^-	-0.003	0.000	-7.252
δ_3^+	-0.005	0.001	-8.303	δ_3^-	-0.004	0.001	-5.676

Table 5.5: Maximum Likelihood Estimates of the Asymmetric Log-ACD Model

We estimate the Asymmetric Log Autoregressive Conditional Duration (Asymmetric Log-ACD) model on FTSE 100 intertrade durations (+1 second) after removing the time-of-day effect. We use duration data for the period from 4 January 2000 to 30 June 2000. We remove the deterministic diurnal component Δ_j where Δ_j represents the mean duration of the time-of-day interval containing x_i and consider the diurnally adjusted series of time durations $\tilde{x}_i = x_i/\Delta_j$. For a definition of the model, see equations (5.23) with (5.24) for a buyer initiated trade, and equations (5.27) with (5.28) for a seller initiated trade. δ_1^+ and δ_1^- are the coefficients of the lagged new day dummy variable. δ_2^+ and δ_2^- are the coefficients of the moving average of the 10 equally weighted lags of diurnally adjusted trading volume. δ_3^+ and δ_3^- are the coefficients of the moving average of the 10 equally weighted lags of diurnally adjusted spread.

5.7 Summary and Conclusions

In recent years, we have witnessed the development of a new wave of high frequency duration models, known collectively as the autoregressive conditional duration (ACD) models. These models account for the irregular spacing characteristic of transactions data. In the original model, Engle and Russell (1998) let the next expected duration depend upon past durations and past expected durations. In this model they assumed the conditional density of the diurnally adjusted durations to be Weibull, which in a special case collapses to the exponential. In a similar manner to Engle and Russell (1998), we apply the exponential and Weibull versions of the ACD model to FTSE 100 transaction durations. Our results indicated that both the exponential and the Weibull versions of the ACD model only partially accounted for the intertemporal correlations occurring in our transactions data. Both versions of the model accept the null hypothesis of no excess dispersion. However we found our estimates of γ to be 1.06 for both the WACD (2,1) and the WACD (2,2) model. This indicates that especially long durations are less likely and we reject the null hypothesis that $\gamma = 1$ for both the WACD (2,1) and the WACD (2,2) model indicating that we prefer the Weibull to the exponential. Thus, in a similar manner to Engle and Russell (1998), we find that the constant proportional hazard of the exponential to be inappropriate for our durations data.

We also proposed a two-state transition model for the trade sign process, where the two states correspond to either to a buyer-initiated trade or a seller-initiated trade, and where the durations are modelled by a Log-ACD process. Additional market microstructure effects were included in the model; these were the past average volume and the past average spread. Our results indicate that γ exceeds one for both states, and again we reject the exponential in favour of the Webull. We also found that as in the EACD and the WACD models, we show strong autoregressive effects, indicating a strong persistence in the dynamics of the duration process, and that the inclusion of volume and spread hardly changes the estimates of the β coefficients. The coefficients of both volume and spread were negative and significant. These results indicated that when average volume per trade increases, the next expected duration becomes smaller and similarly when average spread per trade increases, the next expected duration becomes smaller. Further we found volume for a buyer-initiated trade to be significantly different to volume for a seller-initiated trade in the trade intensity process.

Chapter Six

Conclusions

The literature dedicated to the impact of new information upon financial futures markets is burgeoning. However, most of these studies consider US data, so relatively little empirical work exists on the very high frequency adjustment dynamics of UK futures markets to new information. This thesis addresses this deficiency in the literature by empirically examining the impact of new information upon UK futures contracts traded on LIFFE. In particular we examine the reactions of market microstructure variables in response to two different types of information, namely a macroeconomic news event and the historic pattern of transactions.

One important contribution of this study is the insights provided into the differences between the adjustment process in quote-driven and order-driven markets. The major US markets are specialist markets, where a market maker provides liquidity by posting bid and ask quotes to the trading public. However the UK futures markets are order driven, where traders enter either limit orders or market orders. Given that most studies in this area have looked at US markets, it is clear that relatively little empirical work considers the dynamics of price formation and the trading intensity process in an order driven market. This thesis sets out to address these issues by highlighting the similarities and differences of the dynamics of price formation and trading intensity exhibited in an order driven and a quote driven market.

In chapter two, we examined the impact of repo rate surprises upon prices and trading activity of both the Short Sterling and the FTSE 100 futures contracts. In particular we utilised survey data provided by Reuters of market participants expectations of the forthcoming repo rate announcement as a proxy of the degree of surprise in the market following a repo rate announcement. First, assuming that market participants' forecasts may change during the week of the forecasts being published and the actual announcement release, we performed bias and efficiency tests of the survey data. Our results indicate that while the forecasts appear to be unbiased and efficient, there does appear to be some evidence of a market reaction for the Short Sterling between the time of the survey release and the actual announcement. In our models, we accounted for any market revision by an additional explanatory variable that measures the change in futures price between the time of the survey release and the time of the announcement. As expected this variable was significant in our model of price change for the Short Sterling only. We also indicated that during our sample period, two major environmental changes occurred, namely the tick change for the FTSE 100 and the switch to the electronic trading system from the traditional open outcry, we found these changes to have an impact upon trade volume and its components. We accounted for these changes by including additional dummy variables into our model estimations. We utilised the survey data to extract two measure of the surprise element in the market following a repo rate announcement. In particular for our first measure of the surprise element, we followed Sun and Sutcliffe (2003) and separated our unexpected announcements into unexpected increases and unexpected decreases in repo rate. The second measure of the surprise element utilised information on the proportion of the market that correctly forecast the repo rate announcement as a measure of the market consensus following the release of an announcement. We found that any unexpected change in repo rate leads to a change in price for both contracts and that the response in these two markets to be asymmetric with unexpected increases exhibiting the larger price reaction. In general trading volume was not found to be associated with any surprise in repo rate for the Short Sterling. We suggested, in a similar manner to Kandel and Pearson (1995), that market participants agreed with the announcements implications and therefore did not engage in any additional trading even though a price change occurred. However for the FTSE 100, we found volume to be significantly elevated following a surprise announcement. Additionally, for the FTSE 100 the response in volume was found to be asymmetric with unexpected increases exhibiting the larger volume reaction. Consistent with the uncertain information hypothesis (Brown et al. (1988)), we found volatility became elevated immediately following a surprise announcement, and although volatility returned to normal levels after 5 minutes for the FTSE 100, for the Short Sterling volatility remained persistently higher for at least 60 minutes following an announcement.

In chapter three we provided further evidence on the price and volume adjustment of the Short Sterling and the FTSE 100 futures contracts in response to surprises in repo rate announcements. A major innovation of this chapter is to provide further evidence of the importance of extracting the unexpected components associated with an announcement. Utilising survey data provided by Reuters we determined our measures of the surprise element in the market following a repo rate announcement. We proposed additional measures that better capture the surprise element associated with an announcement. In our first analysis we use the popular method of capturing the difference between the forecast value and the actual announced value as a proxy of whether an announcement is generally expected or not expected. We focused on an announcement window extending from two minutes prior to an announcement to the first ten minutes following an announcement. Our results indicated that following a not-expected announcement both contracts react immediately, exhibiting large price changes, raised volatility and a higher frequency of larger trades. Although for the Short Sterling we found evidence of an initial over-reaction, for the FTSE 100, we found evidence of a delay in reaction and interpreted this as being time where market participants reviewed the implications of the unexpected announcement. Although, we found evidence of a market reaction following an expected announcement, we interpreted this as a consequence of elevated trading activity by a minority of those that did not forecast the expected announcement. Further we found that when an announcement is separated in to its expected and not-expected components, the adjustment process reveals a somewhat different pattern to that found in Ap Gwilym et al. (1998). More specifically we found that following an expected/not-expected announcement prices react more quickly/slowly than that found following an announcement in Ap Gwilym et al. (1998). This indicates that with the majority of the price adjustment being explained by the degree of surprise in the announcement, then the price adjustment processes found in studies such as Ap Gwilym et al. (1998), where announcements are not separated into expected and unexpected components, will have been diluted by the expected component associated with each announcement. This further confirms the importance of capturing the unexpected components associated with an announcement before conclusions are drawn regarding the adjustment process of financial prices to new information.

In our second analysis, we attempt to capture more precisely the surprise elements associated with each announcement. More specifically, utilising Reuters survey data we focus on the proportions of the market that forecasts a repo rate announcement decision either 25 or 50 basis points either side of the actual decision. We estimated three linear regression equations with our surprise elements as our explanatory variables and trade volume, trade frequency and trade size over the first 5-minutes following an announcement as our dependent variables. Our results indicate that for the Short Sterling, following a repo rate announcement much of the observed first 5-minute volume is a consequence of more frequent trading by those who forecast a repo rate announcement 25 basis points above the actual decision. Those participants who forecast a decision 25 basis points below the actual decision also traded more frequently, but their trades were smaller and so had no impact upon volume. Finally those who forecast a decision 50 basis points below the actual decision were found to trade less often. For the FTSE100, much of the observed first 5-minute volume is a consequence of those who forecast a decision either 25 basis points above or below the actual decision. Those who forecast a decision 25 basis points above the decision were found to trade larger amounts more often compared with those who forecast a decision 25 basis points below the decision who were only found to trade more frequently. Although we found those that forecast a decision of 50 basis points from the actual decision explained very little of the observed elevated trading activity in the market following an announcement, we explained this result to be a consequence of the small sample sizes in these 50 basis points from the actual announcement decision.

In chapter four, we generalised Hasbrouck's (1991) VAR model to examine the price formation process of the FTSE 100 futures contract. In a similar manner to Dufour and Engle (2000) we included time-of-day effects and the time between consecutive transactions as additional variables among the determinants of the price impact of a trade and the autocorrelation of trades. A major contribution of this chapter is to examine the role of time in the price formation process of an order driven market. Our results indicate that in contrast to Dufour and Engle (2000) time seems to matter more in the price formation process of an order driven market. In particular we found the time of the UK market open and close, the US open, as well as UK and US announcements to be highly significant. More specifically, we found that a buy transaction arriving after a long time interval has a lower price impact than a buy transaction arriving right after a previous trade. In addition, we found signed trades to exhibit strong positive autocorrelation and a buy order leads to an upward quote revision. In contrast with Hasbrouck (1991) and Dufour and Engle (2000), we found that when quotes are revised in an upward fashion, more buyers enter the market and similarly when quotes are revised in a downward fashion, more sellers enter the market.

In chapter five we model transaction durations using a similar autoregressive conditional duration framework to that first proposed in Engle and Russell (1998). Using FTSE100 futures contract transactions durations data a comparative analysis of both the exponential and the Weibull versions of the ACD model was undertaken. We found that both the exponential and the Weibull only partially accounted for the intertemporal correlations present in our durations' data. We accepted the null of no excess dispersion in both the EACD and the WACD models. In addition we found γ to be 1.06 and that we rejected the null hypothesis that $\gamma=1$, and therefore rejected the exponential in favour of the Weibull.

In chapter four we indicated that a relationship exists between the trade sign process and the trade intensity process. Following this, we proposed a two-state transition model for the trade sign process, where the two states correspond to either to a buyer-initiated trade or a seller-initiated trade, and where the durations are modelled by a Log-ACD process. In addition, we included two additional market microstructure effects; these were the past average volume and the past average spread. Our results indicate that γ exceeds one for both states, and again we reject the exponential in favour of the Webull. We also found that as in the EACD and the WACD models, we find strong autoregressive effects, indicating a strong persistence in the dynamics of the duration process, and that the inclusion of volume and spread hardly effects the estimates of the β coefficients. The coefficients of both volume and spread were negative and significant. These results indicated that when average volume per trade increases, the next expected duration becomes smaller and similarly when average spread per trade increases, the next expected duration becomes smaller. Further we found volume for a buyer-initiated trade to be significantly different to volume for a seller-initiated trade in the trade intensity process.

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