FIVE STUDIES OF THE LONDON INTERNATIONAL FINANCIAL FUTURES AND OPTIONS EXCHANGE

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DECLARATION

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ABSTRACT

This thesis presents five empirical studies of equity and equity index options trading on the London International Financial Futures and Options Exchange (LIFFE). The common theme in this thesis is how an investor can circumvent the problems, or exploit the opportunities, presented by the institutional characteristics of the market. The analysis in all studies is model-independent.

The first study derives boundary conditions for the exercise of the wildcard option on American index options. Necessary conditions are derived for the wildcard to be of value and it transpires that these conditions are met only rarely, implying that the wildcard option is of little significance for these options. A test using the Fleming and Whaley [1994] model, which attributes a significant value to the wildcard option on S&P 100 index options, is consistent with the boundary condition tests in that it also attributes a small value to the wildcard option on LIFFE.

The second study analyses the frictions involved in early exercise. These frictions create different exercise conditions for cash- and delivery-settled options. A set of testable hypotheses of rational exercise practice is derived and tested and the market is found to be largely efficient. Differences are observed between the actions of call option holders and those of put option holders. This is atttributed to a clientele effect, with a greater incidence of inexperienced investors holding call options. A clientele effect is also inferred in the supply of options, with marketmakers taking a larger proportion of the short side of put options.

The third study compares the pricing of the American and European index options traded on the FT-SE 100 index. Boundary conditions are derived and tested and a significant degree of mispricing between the two styles of option is observed. However, the mispricing appears to be unsystematic and a limited test of an *ex ante* trading rule fails to show arbitrage profits. Nevertheless, a modification to observed investor order placement strategy is proposed.

The fourth study considers another aspect of investor order placement strategy: the choice between limit orders and market orders. Limit orders require the investor to take on two types of information risk, but can provide better trading prices than market orders. A strategy is developed and tested which proves effective in controlling the information risks, thus enabling an investor who uses limit orders to capture some of the bid-ask spread.

The final study examines the intraday pattern of the bid-ask spread on the American index options, using a variety of models. Partial conformity and partial violation is observed. It is argued that the standard classification of investors as liquidity or informed traders is inappropriate in the case of index options and that this accounts for much of the observed violation.

In summary, the options market appears to be efficient, in the strict sense that no abnormal risk-adjusted returns have been found. Nevertheless, the thesis finds a number of ways in which investors, given that they are going to trade on the market, can improve their investment performance.

KEY TO SYMBOLS AND ABBREVIATIONS

Symbols

C	The value of a call option
C_{bid}	The closing bid price of a call option
C_n^j	The value at step *n* node *j* of a wildcard-exclusive binomial pricing lattice for a call option
C_n^{*j}	The value at step *n* node *j* of a wildcard-inclusive binomial pricing lattice for a call option
$C_n^{'j}$	The value at step *n* node *j* of a wildcard-inclusive binomial pricing lattice for a call option, excluding the step *n* wildcard
D_t	The value of a dividend paid at time *t*
I_t	The effective spread at time *t*
I_t^{pro}	The proportional effective spread at time *t*
M_n	The market price of option *n* (call or put)
m	The moneyness of an option
N	The number of steps used in a binomial pricing model
P	The value of a put option
P_{bid}	The closing bid price of a put option
P_{target}	An investor's target price for a financial asset
P_t^{ask}	The ask price of an option (put or call) prevailing at time *t*
P_t^{bid}	The bid price of an option (put or call) prevailing at time *t*
P_t^{LA}	The price of a limit ask order for an option (put or call) at time *t*
P_t^{LB}	The price of a limit bid order for an option (put or call) at time *t*
P_t^{MA}	The market ask price of an option (put or call) prevailing at time *t*
P_t^{MB}	The market bid price of an option at time *t*
P_t^{trade}	The transactions price of an option (put or call) at time *t*
p	The probability of an upward movement in the index
Q_t	The quoted spread at time *t*
Q_t^{pro}	The proportional quoted spread at time *t*
q	The proportion of open interest exercised at a given observation
R_{close}	A measure of the success of a limit order, evaluated with reference to the closing price of the option series in question
r	The riskfree interest rate
r^*	The step discount value
S	The value of the underlying asset
S_n^j	The index value at step *n*, node *j* of the binomial pricing lattice
S_{1610}	The value of the FT-SE 100 index at 16.10
S^*	The threshold value of value of *S* for rational exercise (put or call, according to context)
S^*_{call}	The minimum value of *S* for rational exercise of a call option
S^*_{put}	The maximum value of *S* for rational exercise of a put option
T_{abs}	The absolute target spread capture of a limit order
T_{pro}	The p oportional target spread capture of a limit order
t_w	The le 1gth of the wildcard interval
$U(W)$	The uulity obtained from a quantity of wealth, *W*
v	The wildcard period volatility adjustment factor
W	A quantity of wealth
W_n^{Cj}	The value of the wildcard option for day *n* at node *j* of the binomial pricing lattice
X	The exercise price of an option
X^*	The maximum exercise price of a call option at a given ex-dividend event for which early exercise may be rational

α	(1-marginal tax rate) for the recipient of a dividend
$\Delta I_{i,j}$	The change in the absolute effective spread between interval i and interval j
ΔP^{mid}	The change in the midprice of an option
ΔP^{trade}	The difference between transactions prices of an option
$\Delta P_{i,j}^{trade}$	The difference between transactions prices of an option between interval i and interval j
ΔQ	The change in the absolute quoted spread of an option
$\Delta Q_{i,j}$	The change in the absolute quoted spread of an option between interval i and interval j
ΔR_{close}	The change in the measure of success of a limit order by adoption of a different strategy
ΔS	The change in the FT-SE 100 index between the time of quotation of the closing bid price of an option and 16.31
ΔU	The change in utility
θ	The overnight decline in an option price as a consequence of time decay
ζ	The marketmaker's turn on the purchase and exercise of an option
λ	The ratio of the quantity of option 1 (lowest exercise price) to the quantity of option 2 (middle exercise price) used in the construction of a butterfly spread
ΣD	The present value of the dividend stream over the remaining life of an option
σ	The volatility of S
τ	The time to expiry of an option
τ'	A specified interval before removal of unexecuted limit orders

Abbreviations

AAA	Ask-Ask-Ask, a butterfly spread test in which all prices compared are quoted ask prices
ABA	Ask-Bid-Ask, a butterfly spread test in which the price of the option sold short is a quoted bid price and those of the options held long are quoted ask prices
BBB	Bid-Bid-Bid, a butterfly spread test in which all prices compared are quoted bid prices
BS	The Black and Scholes [1973] option pricing model
CBOE	The Chicago Board Options Exchange
CMSW	Cohen, Maier, Schwartz and Whitcomb
GJ	The Geske and Johnson [1984] option pricing model
LIBOR	London Interbank Offered Rate
LIFFE	The London International Financial Futures and Options Exchange, called the London International Financial Futures Exchange until 1992.
LOCH	The London Options Clearing House
LSE	The London Stock Exchange.
LTOM	The London Traded Options Market: control was transferred to LIFFE in 1992.
NYSE	The New York Stock Exchange
OEX	Standard & Poors 100 Index options
SEAQ	The Stock Exchange Automated Quotation system.
S&P	Standard & Poors

Chapter 1

INTRODUCTION

1.1 BACKGROUND

This thesis presents five empirical studies of equity and equity index options trading on the London International Financial Futures and Options Exchange (LIFFE)[1]. Ten years ago, Rubinstein [1985, p 456] wrote "theoretical ingenuity has long since outrun definitive empirical knowledge". Since then, an extensive literature of empirical studies has grown. Nevertheless, the five studies presented here analyse a set of important aspects of options markets, into which little, if any, comparable research has previously been undertaken.

The common theme in this thesis is how an investor can circumvent the problems, or exploit the opportunities, presented by the institutional characteristics of the market. Thus Chapter 3 considers the market frictions involved in the early exercise of options and derives a strategy to minimise the impact of these. Chapter 5 examines the opportunities available to investors through the use of limit orders and develops a strategy to exploit these.

The general approach is first to review the theoretical background to the specific issue being examined; next to consider how theory will be affected by the particular characteristics of the market, then to analyse observed practice in the market to check conformity with theory and finally to examine whether any lack of conformity presents trading opportunities to an investor. Thus Chapter 4 compares the pricing of American and European style options quoted on the principal UK stock index, the FT-SE 100. Theoretical boundary conditions are derived for the relative pricing and these are tested against observed bid-ask quotes. A trading rule is tested for circumstances in which violation is observed and a simple revision to observed order placement strategy is prescribed for index option investors to benefit from any relative mispricing.

[1]Until 1992, the market was operated by the London Stock Exchange as the London Traded Options Market (LTOM). One of the studies in this thesis surveys a period prior to the merger with the London International Financial Futures Exchange which created the London International Financial Futures and Options Exchange.

In the same way, Chapter 6 compares the theoretical and observed behaviour of the bid-ask spread during the course of the trading day: deviation from theory is found, but is not felt to be tradeable for reasons which are presented in the discussion of the results.

Where equivalent research exists, a comparison is undertaken with the results found in the present thesis. For example, Chapter 2 attributes a markedly lower value to the wildcard option embedded in the FT-SE 100 index contracts than is presented in studies of the S&P 100 index options market. Reconciliation of the different values is provided through comparison of the respective intraday volatilities. On the other hand, Chapter 6 finds that the intraday behaviour of the bid-ask spread on FT-SE 100 index options appears to be similar to that of the S&P 100 index options.

The remainder of this chapter is organised as follows: in Section 1.2, an overview of existing research is presented: the market analysed is described in Section 1.3, together with the market for the underlying securities. In Section 1.4 there follows a description of the principal database used in the research. Finally, in Section 1.5, a summary of each study is presented. The five chapters following this introduction present the separate studies and Chapter 7 concludes.

1.2 PREVIOUS RESEARCH

Empirical studies of option prices have taken place side by side with the development of option pricing models. Thus the seminal Black and Scholes [1973] model was first tested by Black and Scholes [1972]. There are now more than 150 published empirical studies of equity and index options markets. The majority of these fall into one of three classifications:

i. efficiency studies,

ii. model tests, and

iii. examination of the information content of the implied volatility.

The allocation of a study to one of the three classifications is made according to the assumptions of the study: thus in efficiency studies (*e.g.* Chance [1986]), the control variable is the option pricing model and the observed variable is the market price, whereas in model tests (*e.g.* Whaley [1982]), the observed variable is the model price (or prices, since many of the tests are comparisons of two or more models) and the control variable is the market price. Implied volatility studies (*e.g.* Merville and Pieptea [1989]), concentrate on what is usually the only unobservable variable in an option pricing model and examine this for issues such as mean-reversion, forecasting power or exercise price bias.

Whilst it is a simple matter to allocate these tests to one of the three classifications above, in general, they are joint tests of three hypotheses:

a. that the model used in the test is valid,

b. that the market tested is efficient, and

c. that the input data are accurate.

Hypothesis *a.* can be eliminated if the test procedure used is model-independent. Such boundary condition tests (*e.g* Bhattacharya [1983]), examine pricing relationships which must hold regardless of the assumptions of any specific option pricing model. As Galai [1983, p50] states, "The market cannot be shown to be inefficient to weak conditions, and, at the same time, efficient for compatible but stronger assumptions". The five studies contained in the present thesis are all model-independent.

The third of the joint hypotheses, namely the validity of the data, is important. Early studies (*e.g.* Galai [1977]) used the last transactions prices observed on a given day of both the option and the underlying security and made the assumption that these were approximately synchronous. Such studies faced three problems:

i. there is a very real danger that the two prices are separated by a time interval so that the information set reflected in one price is not reflected in the other;

ii. no account is taken of which side of the bid-ask spread each price occurs, and

iii. closing prices may be unrepresentative of the market as a whole.

Rubinstein [1985, p456] lamented "Most empirical work ... has suffered from a number of deficiencies, including ... severe limitations created by the use of closing option and stock prices, and limited samples of calendar time or underlying stocks".

More recent studies (*e.g.* Barone-Adesi [1986]), have avoided these problems by using databases such as the Berkeley Options Database, described by Rubinstein and Vijh [1987]. This is a time-stamped record of bid and ask quotes, transactions prices and volumes of options traded on the Chicago Board Options Exchange (CBOE), together with a time-stamped record of the price movement of the underlying asset. Such a high quality database eliminates most of the data validity problems which afflicted early studies.

Some early studies (*e.g.* Chiras and Manaster [1978]) claimed to find market inefficiencies, but Phillips and Smith [1980], following Jensen [1978], point out that market efficiency implies that risk-adjusted returns ***net of all trading costs*** are zero, and that a number of trading costs, in particular the impact of the bid-ask spread, are omitted from these early studies. In general, efficiency studies find that options markets are efficient and model tests find that option pricing models are valid, both within reasonable limits. Two reasons can be offered for this: the researcher's bias and the practitioner's bias.

The researcher's bias can be stated as follows: two axioms of financial research are that, where W represents a quantity of wealth and $U(W)$ the utility derived from W,

$$\frac{dU(W)}{dW} > 0 \;\forall\; W \qquad (1.1)$$

and

$$\frac{d^2U(W)}{dW^2} < 0 \;\forall\; W \qquad (1.2)$$

(1.1) and **(1.2)** respectively define investors as having a non-satiable appetite for wealth and as being risk-averse. The researcher's bias arises from **(1.1)** which effectively prevents the publication of research finding market inefficiency, since a researcher with a non-satiable appetite for wealth would trade any inefficiency found until it disappeared rather than publish its existence. Kalay and Subrahmanyam [1984, p128] appear to be unique in addressing this point.

The second reason is the practitioner's bias. Exchange trading of options commenced at the same time as the Black and Scholes [1973] model was made public. Academic and practitioner expertise have matured alongside each other, with considerable two-way feedback, and it would be surprising if the practitioner were found not to be working more or less in accordance with the prescriptions of the academic.

Standard market-efficiency, model-testing and implied volatility studies have now become well-mined territory. Recent studies (including the five presented in this thesis) have tended to explore more subtle aspects of options markets. Those which are directly relevant to this thesis are discussed in the appropriate chapter, but an overview of the others may give an indication of the range of material offered by options markets.

Many studies examine the interplay between options and stock markets. Hodges [1990] contains a comprehensive review of these. Skinner [1989] finds that stock volatility is reduced and liquidity increased after options have been listed on a stock. Conrad [1988] finds a permanent increase in the stock price during a five day window (three before and one after) of option introduction. Pope and Yadav [1992] find a significant, but small (and hence untradeable), downward pressure on the underlying stocks as options expire. Stephan and Whaley [1990] find that stock prices lead option prices by 15 to 20 minutes, contradicting the expectations of Black [1975] and the empirical findings of Jennings and Stark [1986] and Bhattacharya [1987]. Figlewski and Webb [1990] use an American put-call parity condition to examine the role that put options have in overcoming market restrictions on short selling of stock and find that marketmakers appear to build a small premium into put option prices as a reward for their services in helping investors overcome short selling restrictions.

Other aspects of options marketmaking are considered in Jameson and Wilhelm [1992], who find the costs of discrete hedge rebalancing to be a significant component of the bid-ask spread, Vijh [1990] who finds that option trading on CBOE offers greater depth than stock trading on the New York Stock Exchange [NYSE], but at the cost of wider bid-ask spreads and Dawson and Gemmill [1990], who find excessive risk-adjusted returns available to marketmakers on LTOM.

Gemmill [1990] uses observed option prices to derive an implied probability of a Conservative victory in the 1987 UK General Election. He uncovers a discrepancy between the implied probability incorporated in index option prices and that incorporated in the prices of an index-replicating portfolio of stock options.

1.3 THE MARKET STUDIED

The London Traded Options Market (LTOM) was established by the London Stock Exchange (LSE) in 1978. In 1992, LTOM was merged with the London International Financial Futures Exchange (LIFFE), which was then renamed the London International Financial Futures and Options Exchange (also LIFFE). Initially, American put and call options were offered on a variety of underlying stocks. In 1984, American put and call options were introduced on the FT-SE 100 index and in 1990, European options on the same index were also introduced. For a short period, currency and gilt-edged option contracts were also traded, but these were abandoned through lack of interest.

The list of optioned stocks has changed over time. There have been periods of rapid additions, but also a steady stream of withdrawals, through bankruptcy of the companies (*e.g.* Polly Peck, British & Commonwealth), through takeover of the companies (*e.g.* Hawker Siddeley, Ultramar) or through lack of interest in the options (*e.g.* Vaal Reefs, Land Securities). So-called "restricted life options" have been introduced for short periods on stocks in special circumstances, such as during a takeover bid for a large company. At 14 November 1994, options were listed on 70 underlying stocks.

Options on individual stocks expire quarterly and there are three different expiry cycles, so that each month sees some stock options expire. The expiry months for the American index options are June and December plus additional months to ensure that the nearest four calendar months are always trading. For the European index options, expiry months are March, June, September and December plus additional months to ensure that the nearest three months are always trading. Exercise prices are introduced in response to the price behaviour of the underlying asset, to ensure that investors always have a choice of in-, at- and out-of-the money exercise prices.

Stock option prices are quoted in pence per share, and the unit of trading is a contract which is generally specified in terms of 1,000 shares, although this is altered in the event of a rights or a bonus issue. Index options contracts are priced in index points, which can be converted to sterling at a rate of £10 per index point. Options are not dividend-protected. Transactions on the market are settled in cash by 10.00 the following working day, with the full option premium paid by the taker of the option and margin or cover required from option writers. Exercise of index options is settled in cash also by 10.00 the following day: exercise of stock options is undertaken through the LSE settlement system, which is described in Chapter 3. The daily settlement price for early exercise of American index options is the index value at 16.10. At expiry, the settlement price for index options is the mean of the 15 index values observed between 10.10 and 10.30 on expiry day which remain after the elimination of the three highest and three lowest values.

The market is an open outcry, competitive dealer market, with pit trading. Market hours are 08.35 to the close of a rotation of prices which commences at 16.10. A broker with an order walks into the pit and calls for a quote on the options series in question. Dealers call out two-way prices and the broker trades with the dealer offering the best price. Where two or more dealers quote the same price, the broker has the choice of which gets the order: the accepted custom is to trade with the first dealer to quote the accepted price, although large orders will often be split up among several dealers. The market is an order-driven market and the dealers' quotes are binding only for the instant at which they are delivered[2].

[2]During 1994, LIFFE introduced a continuous indicative pricing system available through quote vendors. This uses an option pricing model to derive indicative bid and ask prices from the current value of the underlying asset. This system, called Autoquote, was not in place during the periods sampled in this thesis.

The underlying stocks are dealt under the Stock Exchange Automated Quotation (SEAQ) system on the LSE. This is a quote-driven market: marketmakers are required to display bid and ask prices which are binding in specified sizes at all times during the mandatory quote period (currently 08.30 to 16.30). The significance of the binding continuous quote system for this thesis is that participants in the options market can be sure of having up to date prices on the underlying security. A marketmaker quoting a binding two-way price on a stock effectively has a short position in an option strangle, with the ask price representing the exercise price of the call option and the bid price representing the exercise price of the put option. Any marketmaker who does not update the quotes on the stocks to reflect all available information will soon suffer from these prices being taken by traders with a more complete information set.

The FT-SE 100 index was introduced in 1984 and has become the most widely quoted of the UK stock market indices. It was set at a base value of 1000 on 31 December 1983 and is recalculated every minute from 08.00 until 16.31. As its name implies, the index is based on the share prices of 100 leading companies: it uses an arithmetic average, weighted by market capitalisation, unadjusted for dividends. The index is calculated from the mid-price of the best quoted bid and ask prices for each stock. Since, as argued above, the constituent stock prices reflect all publicly available information, an index derived from them should also do so. Thus the stale price problem, which can affect US indices which are generally derived from last transactions prices, is absent in the case of the FT-SE 100 index.

Given the importance of the dividend stream to option pricing, it is worth outlining here the pattern of the dividend stream for the optioned stocks and the FT-SE 100 index. The majority of stocks pay dividends twice yearly. They are generally marked ex-dividend on the first day of an account period, which is normally two weeks long[3]. The gross dividend yield on the index is of the order of 4%, which, with an index level of about 2500 points during the period sampled in Chapters 2, 4, 5 and 6, implies a mean ex-dividend fall of about 4 index points on each ex-dividend date. There is some clustering of dividends and during the sample period, extreme values of 1.2 and 8.34 index points were recorded.

One further financial instrument should be mentioned here. There is a FT-SE 100 index futures contract traded on LIFFE. This plays an important role in the pricing and hedging of the index options. The index futures contract expiry months are March, June, September and December, so that in two months out of three, index options expire without an equivalent index futures expiry.[4]

1.4 THE DATABASE

LIFFE kindly provided a database of a similar quality to the Berkeley Options Database described earlier. This is used as the raw material for Chapters 2, 4, 5 and 6 of this thesis. It consists of a time-stamped record of all bid-ask quotes and all transactions prices of all options series traded on LIFFE during two overlapping periods. Each bid-ask quote or transactions price contained in the database is matched with a contemporaneous value of the underlying asset. This value is the index level in the case of index options and the mid-price of the best bid and ask prices quoted for the underlying stock in the case of stock options.

[3]On 18 July 1994, the account system was abandoned by the London Stock Exchange in favour of a ten day rolling settlement system. Stocks are now marked ex-dividend on the first trading day of each week. This means that the ex-dividend pattern for the index is smoother than it was under the account system. Further discussion of the mechanics and implications of this is presented in Appendix 3A following Chapter 3.

[4]Dawson and Gemmill [1990] discuss the implications of this expiry mismatch for index options marketmakers.

The periods covered are the 76 trading days between 23 March 1992 and 10 July 1992 for individual stock options and the 96 trading days between 1 July 1992 and 12 November 1992 for index options. A breakdown of the sample is given in Table 1.1 below.

	Bid-ask quotes			**Transactions**		
	Calls	**Puts**	**Total**	**Calls**	**Puts**	**Total**
Stock options	283,397	225,695	509,092	26,957	11,292	38,249
American index options	60,239	65,141	125,380	14,245	16,223	30,468
European index options	16,666	18,875	35,541	1,348	1,863	3,211
Total	360,302	309,711	670,013	42,550	29,378	71,928

Table 1.1: Breakdown of raw database used in Chapters 2, 4, 5 and 6

A sample of the database is presented in Appendix 1A. It should be noted that, whilst the raw database is time-stamped to the nearest one-hundredth of a second, in the analyses which follow in this thesis, the value is truncated to the second.

From the discussion of the markets presented above, it will be understood that this database avoids the problems which afflicted early studies of options markets. A bid-ask quote is generated on the database every time a participant in the pit calls for one. Since this inevitably happens before a transaction takes place, it is possible to associate each transactions price with the bid-ask quote prevailing at the time. Furthermore, because the LSE is a quote-driven market, and the prices quoted are binding on the marketmakers in reasonable size, it can be assumed that the price of the underlying asset in the database reflects all information publicly available at the time of any given observation in the database.

The different analyses in the following chapters generally call for additional data, such as interest rates, dividends etc. The sources of these data are described in each relevant chapter. Chapter 3 uses a completely separate database, which is discussed in that chapter.

The data are used in tests which are independent of specific option pricing model assumptions, particularly assumptions about the distribution of the underlying asset prices. One drawback of using a finite sample in such an approach is that extreme events or values will tend to be under-represented. However, this drawback is mitigated by the fact that the database described covers the period surrounding so-called Black Wednesday, which occurred on 16 September 1992. Around that date, the UK stock market market showed exceptional volatility, and hence an increase in the representation of extreme events or values.

1.5 SUMMARY OF THE STUDIES

Chapter 2 - The wildcard option

Holders of American index options on LIFFE have a wildcard option which arises from the existence of an interval between determination of the settlement price for the day and the closing time for submission of the exercise notice. During this interval, holders can decide whether or not to exercise their options. Arrival of price sensitive information during this interval will not affect the proceeds of exercise, but will affect the next quoted prices of the options and may consequently affect early exercise practice.

The wildcard option is a portfolio of put options on the option itself, with exercise prices equal to each day's exercise proceeds and with each option having a life commencing at the determination of the settlement price for the day and expiring at the end of the wild card interval. On LIFFE, the wildcard interval lasts for 21 minutes, from 16.10 until 16.31. The wildcard option is of value only in cash-settled options: for delivery-settled options, the value of the proceeds of exercise are not fixed at a point in time, but vary with the movement in the underlying asset.

French and Maberly [1992, p132] state "Pricing the wild card provision becomes a complicated problem because the wild card is a function of its own future value." Diz and Finucane [1994] point out that there is considerable disagreement in the literature over the significance of this option. The key contribution of this chapter is the derivation and testing of simple boundary conditions for the wildcard option. In this way, the strong assumptions necessary in constructing a model to price the complicated option are avoided. The results show that the wildcard option is of limited importance only. This conclusion differs markedly from a number of empirical studies of S&P 100 index options. The Fleming and Whaley [1994] model, which attributes a significant value to the wildcard embedded in S&P 100 index options, is applied to the London market and its results are consistent with those found in the boundary condition tests. Nevertheless, a secondary contribution of this chapter is the highlighting of the high sensitivity which the Fleming and Whaley model has to one specific factor, the **wildcard period volatility adjustment factor**. Analysis reveals that even minor changes in the estimate of the factor produce major changes in the valuation of the wildcard option.

The different results observed in London are attributed to the different volatility characteristics of the two markets. On the US market, virtually all of the market volatility is observed during the trading day, and the volatility during the wildcard interval is only slightly lower than during the remainder of the trading day. On the London market, much of the observed volatility occurs during the overnight closure of the market, and the volatility observed during the wildcard interval is barely one half of that observed during the remainder of the trading day. These differences result in significantly different values attributed to the wildcard period volatility adjustment factor. In their study of S&P 100 index options, Fleming and Whaley attribute an aggregate daily value in excess of $5 million to the wildcard options: the comparable figure in London is found to be less than £50,000.

Chapter 3 - Rational early exercise with market frictions

Early exercise is an aspect of option market efficiency which has received little empirical research. Inefficient early exercise takes one of two forms: the option holder either exercises in circumstances in which this is irrational, or else fails to exercise in circumstances where this would be rational. This chapter extends the theoretical background of early exercise to take account of market frictions. From this, a set of testable hypotheses is derived and these hypotheses are tested against practice by analysis of a database of early exercise.

The form of exercise settlement - cash or delivery of the underlying asset - is found to be a key discriminator in optimal behaviour. The scale of direct transactions charges makes it more economical for both holders and writers of rationally exercised, delivery-settled options to close their positions through market transactions rather than through exercise. Exercise of such options should be undertaken by and against only those investors who wish to use their long or short positions in the options to make a permanent, or semi-permanent, change in their inventories of the underlying stock. Any imbalance between supply and demand will be absorbed by the option marketmakers, who face the lowest transactions costs. In contrast, market frictions serve to encourage exercise rather than market trading to close long and short positions in cash-settled options, since the direct transactions charges are the same whilst the indirect transactions costs encountered in a market sale can be avoided through exercise.

Given the market frictions, five hypotheses of rational early exercise practice are derived. Analysis of market practice reveals largely rational exercise. Where irrational behaviour occurs, it is generally, but not always, to the benefit of the option writers, since option holders exercise in circumstances in which this is not rational. Nevertheless, the incidence of irrational behaviour observed is small, as are the financial consequences. Hence the writer of option contracts may be fortunate enough to obtain a small gain from the irrational behaviour of a counterparty, but the probability and expected size of this gain are too small to permit arbitrage trading. Furthermore, there is one form of irrational behaviour, namely that of exercising delivery-settled options early in an account, which may actually cause financial harm to option writers, since such exercise may force them to incur direct transactions costs greater than those which would result from buying the option back later in the account.

Some of the tests identify marked differences between the put and call option subsamples. No obvious reason is found for these differences. In general put option exercise conforms more closely with hypothesis than does call option practice. This may indicate a clientele effect among option holders, perhaps revealing a greater incidence of inexperienced investors using call, rather than put, options. The predicted contraction of the quoted bid-ask spread on rationally exercised, delivery-settled options, is observed for call options, but not for puts. It is conjectured that this is attributable to a clientele effect in the supply of put options, with a significant proportion of the short positions being held by marketmakers, who have no interest in seeing the bid-ask spread contract.

Chapter 4 - Comparative pricing of American and European index options

LIFFE appears to be unique in trading both European and American contracts on the same underlying stock index (the FT-SE 100). This enables direct comparison of American and European option prices, an aspect of empirical research of equity options markets which appears not to have been undertaken before.

Boundary conditions are derived for the value of the early exercise right and a database of market bid-ask quotes for both American and European options is used to test compliance with these conditions. *Ex post*, a high incidence of violation of the conditions is found. The mispricing appears to be unsystematic and a limited test of an *ex ante* trading rule fails to show abnormal profits.

An irrational investor preference for American options is found and it is argued that a change of order placement strategy would enable investors to take advantage of the observed mispricing and, eventually, to eliminate it. The proposed strategy calls for investors not to restrict their sights to American options but to ask for quotes on two options series, an American one and a nearby European one, and trade in the series which appeared to be more finely priced. It is predicted that such a strategy will lead to an increase in the volume of European options traded and will eradicate the comparative mispricing observed in this chapter.

Chapter 5 - Competing with marketmakers through limit orders

A limit order is an option on a financial asset. With limit bid orders, investors give the market at large the right but not the obligation to sell a fixed quantity of a specified asset at a predetermined price within a specified timeframe - an American put option. A limit ask order has the characteristics of an American call option. The granting of any option involves an assumption of risk, since the option is exercised at the taker's discretion and the taker's interests will generally be opposite to those of the grantor. However, investors who grant options by way of placing limit orders receive no monetary reward for so doing, and thus appear to be unrewarded for their risk. Their gain comes in the form of an opportunity to trade at more advantageous prices than are quoted in the market. In this chapter, the risks and rewards of placing limit orders on LIFFE are analysed.

Limit orders have received considerable theoretical attention, but little empirical analysis. This chapter contributes in several ways: first, two classes of limit order are identified, reflecting the two different roles which they play for investors. Next, it is shown that limit-order investors face very different risks from the marketmakers with whom they are assumed to compete. Finally, using only weak assumptions, a simple trading rule is developed which offers a significant (at the 1% level) increase in the effectiveness of limit order strategy over observed practice, by circumventing some of the risks which limit order investors would otherwise face. This trading rule is tested against advice given by Silber [1988] that public investors on an options market should not attempt to compete with marketmakers and evidence is found to justify rejection of this advice.

Chapter 6 - The intraday behaviour of the bid-ask spread

This chapter compares the intraday patterns observed in the quoted and effective bid-ask spreads on the FT-SE 100 index options traded on LIFFE with a broad range of theoretical models of intraday behaviour. A number of discrepancies are found: it is argued that these discrepancies arise principally because the standard classification of investors into informed and liquidity traders breaks down in the case of index options, in part because options are inappropriate instruments for liquidity traders and also because the concept of an informed trader has a rather different nature in the case of an index as contrasted with an individual stock. Furthermore, marketmakers in these index options have access to a liquid hedging instrument to hedge the risk of asymmetric information.

The key empirical finding in this chapter is that there is a significant contraction of both the quoted and effective bid-ask spreads after the first 25 minutes of the trading day. Subsequently, there is little systematic intraday change in either kind of spread. This contraction is only partially consistent with theory. For example, it conforms with Brock and Kleidon [1992] who forecast inelastic demand for, and supply of, securities at the beginning and end of the day, with a consequent widening of the spread, but the present study finds a widening only at the beginning of the day. It conforms with Foster and Viswanathan [1990], in that the widest spread is seen during the interval with the highest underlying price variance, but their model is based on the idea of a wider spread being a result of a high incidence of informed trading, whereas in the present study, no evidence of informed trading is found during the opening interval.

The existence of the widest spreads during the first session of the day accords with the findings of Mayhew [1993] in another empirical study of an options market and with a point in a review of studies by Lehmann and Modest [1994] that no study of any financial market of which they are aware finds the widest spread of the day at any time other than the market opening. However, their review finds an almost ubiquitous U-shape in intraday spread patterns and the U-shape is absent from the present study.

The existence of significantly lengthy runs of bid- or ask- side transactions is forecast by Admati and Pfleiderer [1989] and this is observed to a high degree of significance. However, it is argued that a different mechanism from that proposed by Admati and Pfleiderer is responsible for these runs. No evidence is found to associate any of the individual intervals examined with bias towards bid- or ask-side transactions.

Finally, one of the motivations for this study was the challenge presented by Sheikh and Ronn [1994, p578]. They ask if there is an optimum time during the course of the day for investors to buy and sell options. The conclusion reached is that there is no such optimum time, but that investors should avoid the opening period of the day, since both the quoted and effective spreads are significantly larger than those at other times with no compensating reward in the form of more informative prices.

Appendix 1A: EXTRACT FROM QUOTE AND TRANSACTIONS DATABASE FOR BRITISH AEROSPACE OPTIONS, 10 JULY 1992

Time	Stock	Expiry	Exercise	Class	Bid	Ask	Trade	Underlying
08:34:07.58	AER	Nov	180	P	4.0	6.0		246.0
08:34:08.37	AER	Nov	200	P	8.0	11.0		246.0
08:34:09.17	AER	Nov	220	P	14.0	19.0		246.0
08:34:09.98	AER	Nov	240	P	22.0	27.0		246.0
08:34:10.59	AER	Nov	260	P	30.0	36.0		246.0
08:34:11.09	AER	Nov	280	P	45.0	55.0		246.0
08:34:14.79	AER	Feb	180	P	5.0	8.0		246.0
08:34:15.34	AER	Feb	200	P	11.0	15.0		246.0
08:34:15.90	AER	Feb	220	P	17.0	22.0		246.0
08:34:16.46	AER	Feb	240	P	27.0	33.0		246.0
08:34:16.97	AER	Feb	260	P	35.0	45.0		246.0
08:34:17.42	AER	Feb	280	P	48.0	58.0		246.0
09:00:55.17	AER	Nov	240	C			33.0	246.0
09:01:02.78	AER	Nov	240	C	29.0	34.0		246.0
09:21:37.43	AER	Aug	360	C	0.0	1.0		245.0
10:24:22.92	AER	Aug	280	P			30.0	245.0
10:43:02.25	AER	Feb	280	C	22.0	27.0		246.0
10:43:36.74	AER	Feb	280	C	22.0	26.0		246.0
10:48:04.37	AER	Feb	280	C	25.0	26.0		246.0

Chapter 2

BOUNDARY CONDITION TESTS OF THE WILDCARD OPTION

2.1 INTRODUCTION

Holders of American index options on the London International Financial Futures and Options Exchange (LIFFE) have a so-called 'wildcard' option. This arises from the existence of an interval between determination of the settlement price for the day and the latest time at which exercise may be declared. During this interval, holders can decide whether or not to exercise their options. Arrival of price sensitive information during this interval will not affect the proceeds of exercise, but will affect the next quoted prices of the options and may consequently affect early exercise practice.

The wildcard option can be viewed as a portfolio of put options on the option itself, with exercise prices equal to each day's exercise proceeds and with each option having a life commencing at the determination of the settlement price for the day and expiring at the end of the wildcard interval. On LIFFE, the wildcard interval lasts for 21 minutes, from 16.10 until 16.31. The wildcard option is of value only in cash-settled options: for delivery-settled options, the value of the proceeds of exercise is not fixed at a point in time, but varies with the movement in the underlying asset.

French and Maberly [1992, p132] state "Pricing the wild card provision becomes a complicated problem because the wild card is a function of its own future value." Diz and Finucane [1994] point out that there is considerable disagreement in the literature over the significance of this option. In this chapter, the significance of the wildcard option on FT-SE 100 index options is analysed through the derivation and testing of simple boundary conditions. The results show that the wildcard option is of limited importance only. This conclusion differs markedly from a number of empirical studies of S&P 100 index options. The Fleming and Whaley [1994] model, which attributes a significant value to the wildcard embedded in S&P 100 index options, is applied to the London market and its results are consistent with the boundary condition tests. In their study of S&P 100 index options, Fleming and Whaley attribute an aggregate daily value in excess of $5 million to the wildcard options: the comparable figure in London is found to be less than £50,000.

The contribution of this study is twofold. First, the difficulties of pricing a complicated embedded option are avoided by the derivation of a set of simple boundary conditions which are sufficient to establish the insignificance of the wildcard option on LIFFE. Second, analysis of the Fleming and Whaley [1994] option pricing model identifies a high degree of sensitivity to the **wildcard period volatility adjustment factor**, and the problems of estimating this factor are considered.

The chapter is organised as follows: Section 2.2 reviews the literature. In Section 2.3, the methodology employed in the analysis is presented, followed by the results in Section 2.4 and a discussion of the results in Section 2.5. Section 2.6 draws together the conclusions.

2.2 REVIEW OF LITERATURE

Published empirical research is confined to the S&P 100 index (OEX) options. The wildcard interval on OEX options now lasts for 20 minutes, from 15.00 until 15.20 Central Time[1]. During this period, the New York Stock Exchange is not trading, but investors can estimate the index level by observing trading of the constituent stocks on other markets and by observing the prices of index futures contracts, most notably the S&P 500 index futures contract, which *are* traded during this interval

French and Maberly [1992] start from the observation that the number of OEX call options exercised early seems too large to be explained by dividend payments. They argue that another factor must be responsible for the observed incidence of early exercise and investigate the properties of the wildcard option. They show that the proportional value of the wildcard option is a negative function of the time to expiry.

[1] Before 6 November 1991, which includes the period covered by some of the literature, the interval lasted only 15 minutes.

In their empirical analysis, French and Maberly regress the incidence of execution (expressed as the ratio of contracts exercised early to the number of contracts open) against the square root of the time to expiry and against the return on the S&P 500 index futures contract during the wildcard interval. In accordance with expectation, both independent factors are found to be significantly negative, although the R^2 statistics obtained are small (0.04 for the full sample and 0.036 for a subsample in which the time to expiry is two weeks or less).

The authors conclude that their results demonstrate that the wildcard option is a statistically significant cause of early exercise, but the results can be regarded as indicative only. The low R^2 values show that the model fails by some distance to capture the process being investigated: the inclusion of a moneyness factor in the model might offer further insight.

Diz and Finucane [1994] also investigate the incidence of wildcard execution of OEX options, in the context of a wider examination of rational early exercise. Like French and Maberly, Diz and Finucane use the return on the S&P 500 index futures contract as a proxy for the return on the S&P 100 index during the wildcard interval. Their database consists of observations of exercise of both put and call options. They use a binomial pricing model to construct *ex post* theoretical prices applying to each observation at the end of the wildcard period and thus identify, *inter alia*, the incidence of execution which is made rational by the existence of the wildcard option. Recognising that the wildcard effect may also interact with the dividend effect, they allocate observations of exercise into different classes for which:

i. the wildcard alone is consistent with rational exercise,

ii. the combined effects of the wildcard and the dividend payment are consistent with rational exercise, whilst neither effect alone is sufficient, and

iii. the wildcard alone and the dividend alone are each consistent with rational exercise.

Their results show that the wildcard effect is necessary (classes *i.* and *ii.*) to rationalise 23.4% of call option observations and 26.1% of put option observations, whilst it is sufficient (as is the dividend payment - class *iii.*) to rationalise a further 2.5% of call option observations and a further 17.2% of put option observations. Hence the wildcard appears to have significant influence on early exercise practice on these options.

Valerio [1993] also starts from the observation that the number of OEX call options exercised early cannot be rationalised by dividend payments and postulates the wildcard feature as the reason for the observed incidence of early exercise. He then develops a discrete-time model with two state variables to value call options with the wildcard feature. With the assumptions made in the numerical examples presented (no dividends, time to expiry = 10, 20 and 30 days, riskfree interest rate = 7% and annual standard deviation of return = 20%) Valerio's model values the wildcard feature at up to 1.4% of the value of an otherwise similar American call option.

Fleming and Whaley [1994] develop a binomial model to value the wildcard option. The model is described briefly in Appendix 2A, since one important factor in this model is used to reconcile the results of the boundary condition tests on FT-SE 100 index options contained in this chapter with the results of the model-dependent tests of OEX options which Fleming and Whaley report. Using some rather strong assumptions, they use this model to isolate the incremental value which the wildcard option contributes to OEX options, and find a value in excess of $5 million for a single day's trading. They find the value of the wildcard option to be approximately equal for put and call options with identical moneyness and time to maturity values. In general, the value of the wildcard option is a monotonically increasing function of time to maturity but its relative contribution is a decreasing function for both put and call options. Similarly, the value of the wildcard option is generally an increasing function of the extent to which it is in the money and the relative contribution is equally a decreasing function. However, for short dated, deep in the money put options, which are almost certain to be exercised early independent of the wildcard option, the value of this option decreases with moneyness.

In contrast, Harvey and Whaley [1992], in a study of implied volatility prediction, attribute little value to the wildcard option embedded in the options within their sample, which is restricted to at the money OEX puts and calls with at least 15 days to expiry. They also use the return on the futures contracts as a proxy for the return on the index during the wildcard interval and find a 95% confidence interval of (-0.336%, +0.384%). Even the maximum decline within this confidence interval is insufficient to outweigh the time value of a 15 day at the money call option, using typical parameter values of volatility = 20%, riskfree interest rate = 8% and dividend yield = 4%.

In summary, four of the five published studies on OEX wildcard options attribute significant value to it. The exception is Harvey and Whaley [1992] who restrict their sample to at the money options. Nevertheless, as Diz and Finucane [1994] point out, there is still considerable disagreement over the precise significance of the option. The Fleming and Whaley [1994] model, summarised in Appendix 2A, provides a straightforward adaptation of the binomial model of Cox, Ross and Rubinstein [1985] to incorporate the wildcard option, but poses two specific problems:

i. it restricts the number of steps in the iterative process to the number of days remaining for the option, which therefore produces a coarse lattice, especially in short-dated option valuation, and

ii. it is particularly sensitive to the value of the wildcard period volatility adjustment figure.

2.3 METHODOLOGY

The approach

In this chapter, a different approach is adopted from that taken in a number of the studies of the OEX options. Valerio [1993], French and Maberly [1992] and Diz and Finucane [1994] approached the problem thus: can the surprisingly high observed incidence of early exercise be rationalised by attaching a significant value to the wildcard option? In their different analyses, all authors concluded that the wildcard option does rationalise observed exercise behaviour.

The present study addresses a different question: how much is early exercise practice likely to be affected by the observed performance of the index during the wildcard interval? The objective is to isolate all instances in which changes in the index during the wildcard interval may affect early exercise practice. A model-independent approach is used in which necessary, although not sufficient, boundary conditions are established for early exercise practice to be affected by such changes. Fleming and Whaley [1994] consider a similar question for OEX options, but in a model-dependent context.

The database

The database analysed in this study is extracted from that described in Section 1.4. It consists of closing bid-ask quotations for in the money American put and call options on the FT-SE 100 index for 96 consecutive trading days from 1 July 1992 until 12 November 1992. These quotations are matched with the simultaneous value of the FT-SE 100 index and the value of the index at 16.31, which is the end of the wildcard interval. There are a total of 7,121 observations, broken down as shown in Table 2.1 below:

	In the money at 16.10	In the money at 16.31
Calls	3,239	3,243
Puts	3,882	3,874
Total	7,121	7,117

Table 2.1: Composition of database

Additionally, a minute by minute record of the FT-SE 100 index throughout each of the 96 trading days is used in the analysis. These data were supplied by LIFFE.

Methodology

Exercise of cash-settled options is entirely analogous to sale in the market. In either case, the position is closed and cash is received on the next business day. Unlike exercise of delivery-settled options, there is no transfer of a risky asset. Thus the option holder's strategy is quite simple. If it is desired to close a position during the day, sale in the market is optimal, because the exercise proceeds are not yet known. If the investor wishes to close the position at the close of the option market, two values are available: the exercise proceeds or the closing option bid price. The closing prices are quoted after the determination of the exercise proceeds and clearly the investor seeking to close a position will undertake a market sale if the option bid price exceeds the exercise proceeds and exercise otherwise.

The objective in this study is to isolate those instances where early exercise practice may be altered by the wildcard option. There are three conditions under which such alteration may take place, referred to in this chapter as **maximum delta**, **spread avoidance** and **exercise deferral**.

Maximum delta

Consider the following examples, taken from the database. In the first case, on 4 August the closing bid price for an August 2250 call option was 160. The price was quoted at 16.12, when the index value was 2409.1. The 16.10 value of the index was 2409.4, so that the proceeds of exercise were 159.4. Thus at 16.12, a rational investor might choose to hold the option or to sell it at the bid price of 160, but would not choose to exercise it because the proceeds of exercise were lower than the market bid price. Assume the investor chose to hold the option. By 16.31, the value of the index had fallen by 2.4 points to 2407.5 after the closing bid price was quoted. At this point, the investor's choice was between holding the option overnight and exercising it for a value of 159.4. Assuming an option delta of 1, the implied bid price of the option was 157.5[2]. Since this was below the proceeds of exercise, it is assumed that the investor chose to exercise the option.

Without the wildcard option, the 16.31 choice would not have been available to the investor, who would have been forced to hold the option overnight. Hence, in the circumstances described in this case, the existence of the wildcard option altered investor behaviour.

[2]The implied price has been rounded to the nearest ½ point, which is the minimum unit of price for these options.

In the second example, on 24 September, the closing bid price for a November 2750 put option was 139. The price was quoted at 16.21, when the index value was 2615.6. The 16.10 value of the index was 2611.2, so that the proceeds of exercise were 138.8. The 16.31 value of the index was 2621.2, so it rose by 5.6 points after the closing bid price was quoted. Assuming an option delta of -1, the implied bid price of the option fell to 133.5. Since this was below the proceeds of exercise, again it is assumed that the wildcard option was exercised.

Thus maximum delta exercise of the wildcard option is assumed to take place on all occasions when ever the implied fall in the market bid price of an option resulting from the index movement during the wildcard interval is greater than the excess of the closing bid price over the proceeds of exercise. In calculating the implied bid price, no value has been ascribed to the overnight fall in value of the option through time decay. This is because the overnight time decay of an option which is very close to being rationally exercised is very small. Thus in the call option example above, with the index held constant, the option value would decay by a total of 0.6 points over the remaining 17 days of its existence from the time of the closing bid quote and in the put option example, again holding the index constant, the decay would amount to 0.2 index points over the remaining 57 days of its existence. It will be recalled that the minimum price movement for an index option quote is ½ index point.

To put these assumptions into more formal terms, let P_{close}^{MB} be the closing bid price of an option, ΔS, the change in the index level between the time of the closing bid and the market close, S_{1610}, the value of the index at 16.10, X, the exercise price and θ, the overnight change in the option value through time decay. A delta value of 1 for calls and -1 for puts is assumed and wildcard exercise is assumed to occur if either of the following conditions is met:

Call options:

$$P_{close}^{MB} > S_{1610} - X \cap P_{close}^{MB} + \Delta S + \theta < S_{1610} - X \qquad \textbf{(2.1)}$$

Put options:

$$P^{MB}_{close} > X - S_{1610} \bigcap P^{MB}_{close} - \Delta S + \theta < X - S_{1610} \tag{2.2}$$

For reasons explained above, a value of $\theta = 0$ is assumed in the tests which follow.

Spread avoidance

Circumstances can arise in which the closing quoted bid price for an option is less than the proceeds of exercise. As options approach the point at which it becomes rational to exercise them, the value of the option in a frictionless market is close to $S - X$ for calls and $X - S$ for puts. However, marketmakers quoting a price on such options must expect a turn and will thus bid below $S - X$ or $X - S$. Hence holders of index options who wish to close their position will be motivated by the bid-ask spread to exercise rather than to sell, since the proceeds of exercise exceed the market bid price.

Two examples of this follow. First, on 3 September at 16.14, the closing bid price of October 2850 Puts was quoted at 465, when the index stood at 2381.0. The 16.10 value of the index was 2381.9, so the proceeds of exercise were 468.1, 3.1 points higher than the closing bid price. Thus the rational investor might choose to hold the option or to exercise it, but would not choose to sell the option. Assume that the value of the exercise proceeds, 468.1 points, represent the exact point of indifference for an option holder between holding the position and closing it and that the decision was made to hold the position. Any positive movement in the index between the time of the closing quote and the expiry of the wildcard option for the day will decrease the implied put option price and hence motivate the option holder to exercise the option rather than continue to hold it since the implied price has moved below the point of indifference. As it transpired, the index rose to 2384.3 at the close, thus triggering the assumed exercise which would not have taken place without the existence of the wildcard option.

Second, on 12 November at 16.13, the closing bid price of November 2300 Calls was 227 when the index stood at 2728.3. The 16.10 value of the index was 2727.9, so the proceeds of exercise were 227.9, 0.9 points higher than the market bid price. Assume an option holder indifferent between retaining and closing the position at a value of 227.9. Any negative movement in the index before the end of the wildcard interval will trigger wildcard exercise. The index closed at 2726.4, again triggering the assumed exercise which would not have taken place without the existence of the wildcard option.

This study aims to isolate the marginal impact on exercise practice which the wildcard option induces, hence the assumption about the proceeds of exercise marking the point of investor indifference. With such an assumption, any negative movement of the index during the wildcard interval will trigger exercise of call options and any positive movement will trigger put option exercise. Thus the conditions for wildcard exercise through spread avoidance are:

Call options:

$$P_{close}^{MB} \leq S_{1610} - X \bigcap \Delta S < 0 \qquad \textbf{(2.3)}$$

Put options:

$$P_{close}^{MB} \leq X - S_{1610} \bigcap \Delta S > 0 \qquad \textbf{(2.4)}$$

Exercise deferral

There is a third circumstance in which the wildcard option may affect early exercise practice, and this has received little or no attention in the literature. Consider the following observations, again taken from the database. First, at 16.11 on 6 October, the closing bid price for October 2150 Calls was 335 and the 16.10 index level was 2485.5, yielding exercise proceeds of 335.5. Without the wildcard option, a holder of these options might rationally choose to exercise, since the exercise proceeds exceed the market bid price. However, between the time of the closing quote and the end of the wildcard interval, the index rose by 3 points and, assuming a delta of 1, the implied option value rose to 338. Hence with the wildcard option, the investor could rationally choose to hold the position and capture the market rise.

Second, at 16.14 on 10 September, the closing bid price for September 2700 Puts was 356 and the 16.10 index level was 2343.3, yielding exercise proceeds of 356.7. Without the wildcard option, a holder of these options might choose to exercise. However, between the time of the closing quote and the end of the wildcard interval, the index fell by 2.6 points and, assuming a delta of -1, the implied price of the option rose to 358.5. Hence a holder might choose to defer exercise in order to capture the market fall.

To ensure inclusion of all possible effects of the wildcard option, an option delta of 1 for calls and -1 for puts is again assumed. It is also assumed that, in those cases where the closing bid price is below the exercise proceeds, option holders will defer exercise if the index movement during the wildcard interval is sufficient to raise the implied bid price above the exercise proceeds. This is the converse of the maximum delta condition described earlier. Algebraically, the conditions for exercise deferral as a consequence of the existence of the wildcard option are:

Call options:

$$P^{MB}_{close} < S_{1610} - X \bigcap P^{MB}_{close} + \Delta S > S_{1610} - X \qquad \textbf{(2.5)}$$

Put options:

$$P^{MB}_{close} < X - S_{1610} \cap P^{MB}_{close} - \Delta S > X - S_{1610} \quad \textbf{(2.6)}$$

The assumptions made in the maximum delta, spread avoidance and exercise deferral conditions are strong but comprehensive. The wildcard option can affect exercise practice (either triggering it or deferring it) only if one of these three conditions is met. The methodology adopted in this paper is first to examine the level of market activity during the wildcard interval and then to test each of the closing bid prices for compliance with these three conditions and to analyse the incidence of compliance. It will be noted that conditions **(2.1)** to **(2.6)** are mutually exclusive: an observation cannot comply with more than one of them.

2.4 RESULTS

Market activity during the wildcard interval

The proportionate daily return on the index during the wildcard interval is first examined. The data are presented in Appendix 2B and summarised in Figure 2.1 below, which shows that the market is generally very quiet across this interval.

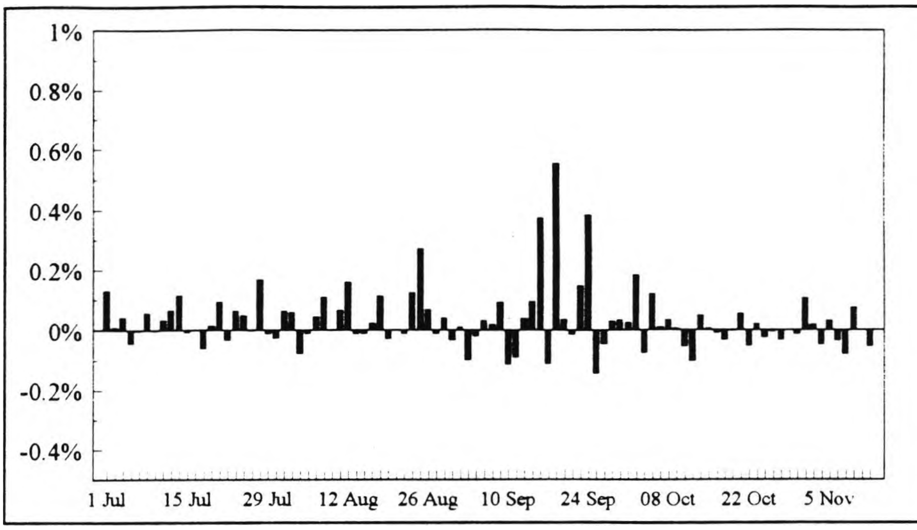

Figure 2.1: Changes in the index level between 16.10 and 16.31 for each of the days sampled

With the exception of the period around September 16, which became known as "Black Wednesday" because of turbulence in the currency markets, the changes were very small. Overall, the mean return was 0.0297%, similar to the value found by Harvey and Whaley [1992] for the return on the S&P 500 futures contract during the OEX wildcard interval. The mean size of the absolute value of the change was 0.065%. This is developed further by examination of the standard deviation of returns on the index in 20 minute intervals throughout the day from 08.30 until 16.30. The data are presented in Appendix 2C and summarised in Figure 2.2 below.

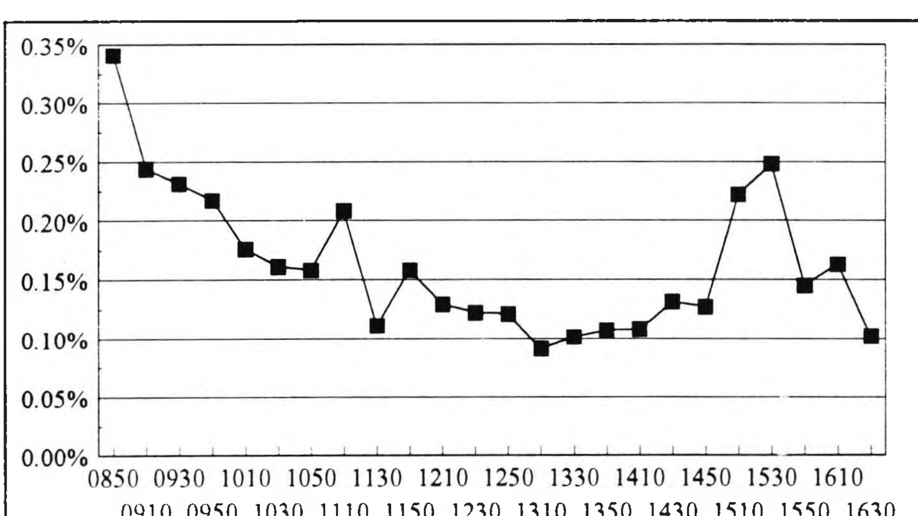

Figure 2.2: Standard deviation of index returns by 20 minute intervals

Figure 2.2 shows that the volatility in the London market across the wildcard interval (16.10 to 16.31) is low compared with the remainder of the day. The 95% confidence interval for the return during the wildcard period is (-0.17%, 0.23%), and the width of this confidence interval is barely one half of that which Harvey and Whaley [1992] found for the S&P 500 futures contract, even though the London wildcard interval is 6 minutes (40%) longer than that applying to the Harvey and Whaley analysis. In general, little new information is released on the London market during this period: government statistics are generally released at 09.30, company results are generally announced either early in the morning or at lunchtime, just ahead of the opening of the New York Stock Exchange. The wildcard interval coincides with late morning trading in New York, which itself appears generally to be a fairly quiet period, casting little influence on the London market. This inactivity in the London market implies that the wildcard option is likely to have little influence on rational exercise activity.

Results of maximum delta condition test

To qualify for this test, an observation has to be in the money at 16.10 and with a closing bid price higher than the proceeds of exercise. The database gives a sample of 3,120 call options and 3,286 put options which qualify. The results show rational exercise of the wildcard option for 9 observations of call options (0.29%) and 13 observations of put options (0.40%). Thus the maximum delta test shows an almost complete lack of value for the wildcard option.

Results of spread avoidance condition test

In the closing bid-ask quotations under analysis in this study, there are 715 observations of in the money options where the proceeds of exercise exceed the closing bid price. Of these, 119 are call options, representing 3.7% of the sample of in the money call options. The remaining 596 are put options and represent 15.4% of the put option sample. Any negative movement in the index during the wildcard interval is assumed to trigger wildcard exercise of call options and any positive movement is assumed to trigger wildcard exercise of put options. Such movements are observed in 51 cases for call options (1.6%) and 216 cases for puts (5.6%).

Results of exercise deferral test

As with the spread avoidance test, only those closing bid prices which are below the proceeds of exercise qualify for this test, so the same 715 observations are tested. There are 30 observations (0.9%) of call options which comply with the criterion and 59 observations (1.5%) of put options.

Table 2.2 below summarises the maximum incidence of execution of the wildcard option under the assumptions made:

	Calls		**Puts**		**Total**	
	n	**%**	**n**	**%**	**n**	**%**
Sample size	3,239	100.00	3,882	100.00	7,121	100.00
Maximum delta exercise	9	0.27	13	0.33	22	0.30
Spread avoidance exercise	51	1.57	216	5.52	267	3.75
Exercise deferral	30	0.92	59	1.52	89	1.25
Total	90	2.78	288	7.42	378	5.31

Table 2.2: Maximum incidence of wildcard option effects

Under the twin assumptions that the delta of call option never exceeds 1 and that of a put option is never less than -1, the three conditions embrace all possible wildcard influence and the maximum incidence of wildcard influence identified in Table 2.2 is small. It appears that the wildcard option on FT-SE 100 index option contracts is of little significance.

Characteristics of the exercised options

The significance of those options whose wildcard is assumed to influence exercise practice is reduced still further by an analysis of their moneyness and time to maturity characteristics. The moneyness of an option is defined as 100(*S/X - 1)* for calls and 100(1 - *S/X*) for puts. Table 2.3 below summarises the mean moneyness and time to maturity characteristics for the options affected under the three conditions derived above.

	Calls		Puts		Total	
	Moneyness	**Days to expiry**	**Moneyness**	**Days to expiry**	**Moneyness**	**Days to expiry**
Maximum delta	11.62	14.00	6.13	51.08	8.37	35.91
Spread avoidance	15.13	12.18	11.01	52.90	11.80	45.12
Exercise deferral	12.89	11.49	10.27	63.00	11.16	45.62
Total	14.03	12.11	10.64	54.88	11.45	44.70

Table 2.3: Mean moneyness and time to maturity characteristics of affected sample

These characteristics are shown graphically in Figures 2.3 and 2.4 below.

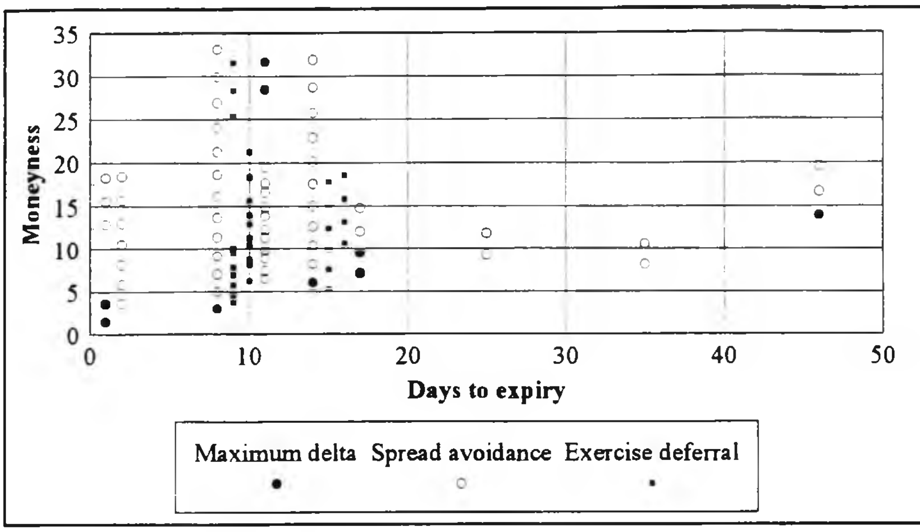

Figure 2.3. Moneyness and time to maturity characteristics of call options affected by the wildcard option

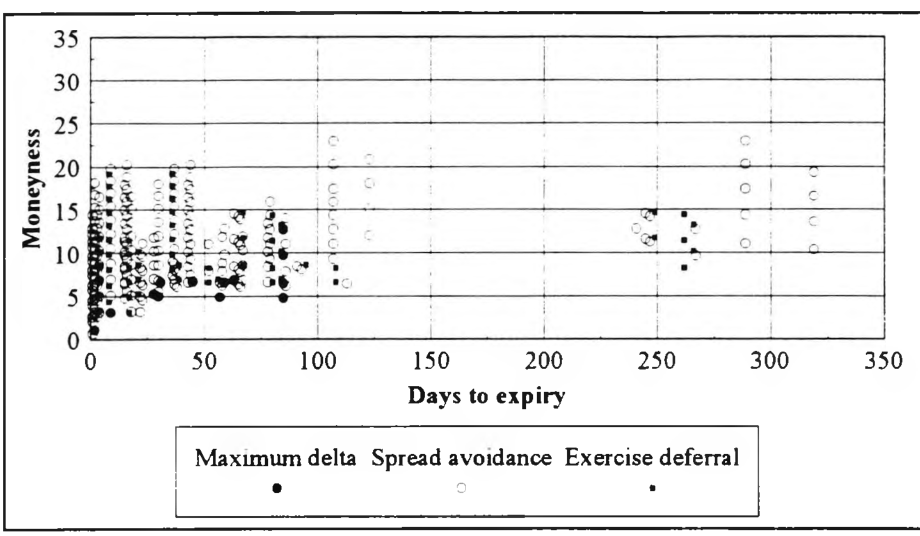

Figure 2.4. Moneyness and time to maturity characteristics of put options affected by the wildcard option

Figures 2.3 and 2.4 and Table 2.3 show the wildcard to be effective only on deep in the money options. 92% of the call options affected and 91% of the put options affected have moneyness values of 5 or more. With a mean index value over the sample of almost 2500, this implies that they are generally in the money by at least 125 index points. Such options are rarely traded. Over the sample period, there were 14,245 transactions in call options and 16,223 in puts. Of these only 617 calls (4.3%) and 634 puts (3.9%) were of options which had a moneyness value of 5 or more. The vast majority of options traded are out of the money, at the money or slightly in the money: from the evidence of this study, the wildcard only becomes material when the option is deep in the money.

2.5 DISCUSSION OF RESULTS

The results presented in Section 2.4 differ markedly from the results of the published studies of OEX options. The US studies generally show a significant value for the wildcard feature, whereas the tests in Section 2.4 show this to have an insignificant value on the London market.

Some reconciliation can be found through analysis of the Fleming and Whaley [1994] model, which is summarised in Appendix 2A. In their paper, and in Appendix 2A, it is shown that the model is highly sensitive to the estimate of v, the **wildcard period volatility adjustment factor**. Fleming and Whaley determine an empirical value of 1.6 from a 10 year history of the S&P 500 index futures contract. Their analysis of volatility ratios, presented in Table IV of their paper, is detailed, covering not only the entire 10 year history of their sample, but also providing values for each year and for the trading day, overnight and close to close volatility ratios. It is of interest to compare these values with their equivalent values from the London database used in the present study. The values for London need to be calculated with reference to the different lengths of the intervals analysed: thus the wildcard interval in London is 21 minutes long, while the US interval was 15 minutes long during the period covered by the Fleming and Whaley database. The London trading day lasts 8 hours (6¾ hours) and thus the London overnight interval is 16 hours long (17¼ hours).

Table 2.4 presents the London data and compares them with the values found by Fleming and Whaley for:

i. the full sample,

ii. the first 61 trading days of 1991, being the closest period they have to the period sampled in the present study, and

iii. the maximum and minimum values recorded in any individual calendar year.

	FT-SE 100 1992	**S&P 500 full sample**	**S&P 500 1991**	**S&P 500 Maximum**	**S&P 500 Minimum**
Observations	96	2,255	61		
Standard deviation					
Trading day	0.970%	1.022%	1.027%	1.472%	0.655%
Wildcard interval	0.102%	0.180%	0.156%	0.325%	0.113%
Overnight	0.812%	0.405%	0.448%	0.562%	0.203%
Close to close	1.216%	1.105%	1.112%	1.650%	0.704%
Volatility ratios					
Trading day	0.50274	0.91517	0.78929	1.14725	0.63615
Overnight	0.84932	3.69183	2.89249	5.03308	2.89249
Close to close	0.69461	1.59605	1.37453	1.92990	1.14852

Table 2.4. Standard deviations and volatility ratios for different intervals for FT-SE 100 index in 1992 and S&P 500 index futures contract over 10 year history, 1982 - 1991.

Table 2.4 shows not only that the intraday composition of volatility is significantly different between the FT-SE 100 index and the S&P 500 index futures contract but also that the intraday composition of volatility for the latter changes over time. Comparison of the standard deviations is complicated by the different lengths of the intervals analysed, but these are standardised in the calculation of the volatility ratios.

The empirical determination of a value of 1.6 for v in Fleming and Whaley [1994] can be seen from the final row. The close to close volatility ratio is calculated as 1.59605. This shows that, on a unit time basis, the mean volatility observed in the wildcard interval for the S&P 500 index futures contract was 60% greater than the mean close to close volatility. However, it will be seen from the other S&P 500 columns in Table 2.4 that this volatility ratio is itself volatile, with extreme values of 1.15 and 1.93 for the calendar years surveyed. Given the sensitivity of the Fleming and Whaley model to this factor, it appears imprudent to use a value derived over such a long period as input to the model. A value derived over a shorter period would better reflect current information. This estimation problem is similar to that of estimating the value of σ in standard option pricing models.

More relevant to the present study, however, is the comparison of the FT-SE 100 index value with any of the S&P 500 values. Fleming and Whaley envisaged a lower bound of 1 for this factor, which describes a situation in which, again on a unit time basis, the mean volatility of the wildcard interval equals the mean close to close volatility. Table 2.4, though, shows a value of 0.69,[3] implying that the mean volatility of the 21 minute wildcard interval is less than 70% of the mean close to close volatility.

Examination of the other volatility ratios bears this point out. The standardised volatility of the wildcard interval on the S&P 500 index futures is 91% of the standardised trading day volatility, whereas the equivalent figure for the FT-SE 100 index is just over 50%. Similarly, Table 2.4 shows that the standardised wildcard interval volatility for the S&P 500 index futures is 369% of the standardised overnight value, whereas the equivalent figure for the FT-SE 100 index is less than 85%. In other words, on a unit time basis, the London market is more volatile during the overnight close than during the wildcard interval.

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[3]The database used in the present study includes a week of exceptional volatility; so-called 'Black Wednesday' occurred on 16 September 1992. Omission of this week's data from the analysis reduces the estimate of v still further - to 0.62.

This has a significant effect on the valuation of the wildcard option on LIFFE. Figure 2.5 below shows the difference (in index points) between wildcard-inclusive and wildcard-exclusive valuations of a call option, priced using the Fleming and Whaley [1994] model with the following parameters: $S = 2500, X = 2500, r = 0.1$, and $\sigma = 0.1923$. These are all typical values taken from the database examined in this chapter. To keep matters simple, no dividends are assumed and a range of times to expiry are used, from 10 days to 60 days. The values of v analysed are 0.69 (the empirical value observed for the FT-SE 100 index in Table 2.4), 1 (Fleming and Whaley's lower bound), 1.6 (the empirical value observed for the S&P 500 index futures contract in Table 3.4), 1.73 (the Fleming and Whaley upper bound for the FT-SE 100 index, calculated as $\sqrt{(24/8)}$, since the trading day in London lasts 8 hours) and 1.9, (the Fleming and Whaley upper bound for the S&P 500 index futures contract, calculated as $\sqrt{(24/6.75)}$, since the trading day for the S&P 500 index futures contract lasts 6.75 hours).

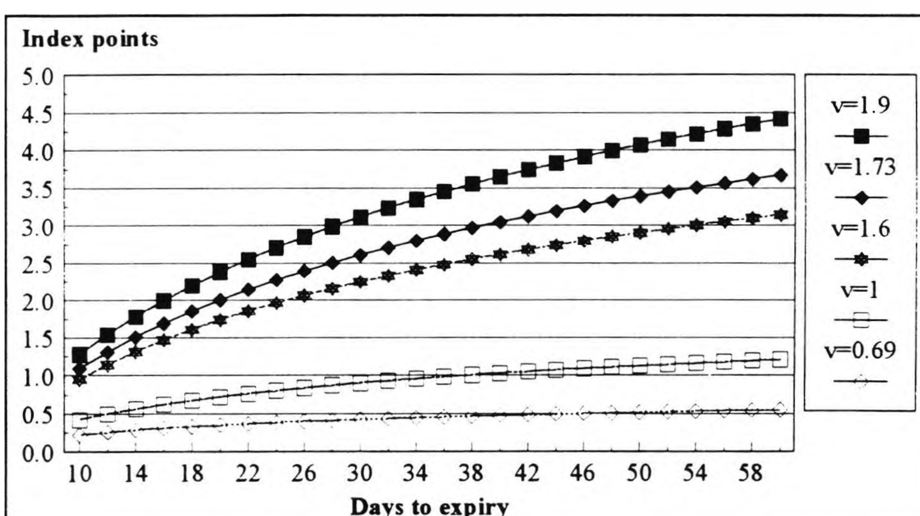

Figure 2.5. The value of the wildcard feature embedded in a call option with parameters $S = 2500, X = 2500, r = 0.1, \sigma = .1923$ and different values of v.

The sensitivity of the Fleming and Whaley [1994] model to the value of v is emphasised in Figure 2.5. Using the stated parameters, the value of a 30 day at the money option is 2¼ index points when $v = 1.6$, but less than ½ index point when $v = 0.69$. Since ½ index point is the minimum price change permitted on FT-SE 100 index options, it will be seen that the Fleming and Whaley model attributes an insignificant value to the wildcard feature embedded in FT-SE 100 index options, and this result is consistent with the results of the boundary condition tests described in Section 2.4.

Figure 2.6 below shows the values of the wildcard option across a range of exercise prices, using the parameters: $S = 2500$, $r = 0.1$, $\sigma = 0.1923$ and $v = 0.69$, with no dividends and a range of times to expiry, from 10 days to 60 days. Even for a long dated, deep in the money option, the value is less than 1 index point.

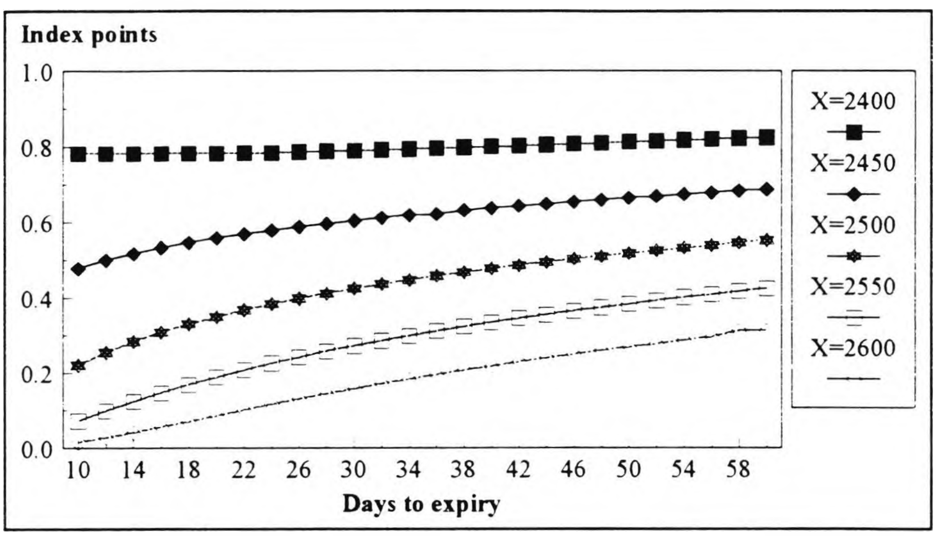

Figure 2.6. The value of the wildcard feature embedded in a call option with parameters $S = 2500$, $r = 0.1$ and $\sigma = .1923$, $v = 0.69$ and different values of X.

Using some rather strong assumptions, Fleming and Whaley [1994] calculate a mean aggregate daily value for the wildcard feature embedded in OEX options as greater than $5 million. Using the equivalent assumptions for FT-SE 100 index options (0.424 points per contract, £10 per index point per contract, 10,000 contracts per day), the aggregate daily value for the wildcard feature embedded in FT-SE 100 index options is less than £50,000.

2.6 CONCLUSION

In this study, the significance of the wildcard option on FT-SE 100 index options is evaluated empirically by analysis of the movement of the index during the wildcard interval. If exercise of the wildcard option is to be rational, one of two boundary conditions must be met: either the fall in the implied option price over the wildcard interval must exceed the difference between the closing quoted bid price of the option and the exercise proceeds, or, in cases where the closing quoted bid price is less than the exercise proceeds, the change in the implied option price during the wildcard interval must be negative. A further effect which the wildcard option might have on exercise practice is exercise deferral. For this to take place, the increase in the implied option price over the wildcard interval must exceed the difference between the exercise proceeds and the closing quoted bid price. The implied option price is derived by applying the maximum option delta of 1 for calls and -1 for puts to the change in the index between the time of the closing option quote and the end of the wildcard interval.

Thus there exist three simple and testable boundary conditions for the wildcard option to have any effect on exercise practice. Empirical analysis shows that the spot index is generally quiet during the wildcard interval which leads to a low incidence of compliance with these conditions. Those observations which meet the conditions are characterised by a high moneyness factor and are infrequently traded. Put options comply more frequently than call options.

Overall, the conclusion is that the wildcard option is of little significance for FT-SE 100 index options on LIFFE. This conclusion differs greatly from a number of empirical studies of OEX options. The difference is attributed to the different intraday volatility characteristics of the two underlying indices. The S&P 500 index futures contract, which is used by most authors as a proxy for the S&P 100 index, is characterised by a concentration of volatility within the trading day, with only a small (< 10%) decline in volatility during the wildcard interval and very little volatility during the market close.

In contrast, the FT-SE 100 index shows a smaller concentration of volatility during the trading day, but a much larger (*c* 50%) decline in volatility during the wildcard interval and a higher level of volatility during the market close. In fact, the London market is more volatile overnight than during the wildcard interval.

The effect of this is to create a very low value for the wildcard period volatility adjustment factor (v) used in the Fleming and Whaley [1994] model. The model is very sensitive to this factor and application of the observed value of 0.69 for v indicates that the model will attribute an insignificant value to the wildcard feature in London. Thus whilst Fleming and Whaley attribute an aggregate daily value of greater than $5 million for the wildcard option embedded in OEX options, the equivalent figure for the FT-SE 100 index options is less than £50,000. Hence it appears that the Fleming and Whaley model is consistent with the results of the boundary condition tests employed in this chapter

Appendix 2A: THE FLEMING AND WHALEY [1994] MODEL

The model

The Fleming and Whaley [1994] model involves two adaptations to the well-known binomial model of Cox, Ross and Rubinstein [1985]. First, the number of time steps, N, is selected to match the number of days to expiry. Second, at each step in the pricing of a call option[4], ($n = 1..N - 1$), of the lattice, the value at each node, ($j = 1..n$), which in a wildcard-exclusive valuation is defined as:

$$C_n^j = \max[S_n^j - X, \frac{pC_{n+1}^j + (1-p)C_{n+1}^{j+1}}{r^*}] \tag{2.7}$$

is replaced by:

$$C_n^{*j} = \max[S_n^j - X, \frac{pC_{n+1}^{*j} + (1-p)C_{n+1}^{*j+1}}{r^*} + W_n^{C^j}] \tag{2.8}$$

where C_n^j represents a wildcard-exclusive call option value at node j, step n of the lattice, S_n^j the index value, X the exercise price, p the probability of an upwards movement in the index and r^* the step discount value. C_n^{*j} represents the equivalent wildcard-inclusive value and $W_n^{C^j}$ represents the value of the wildcard option for day n at node j of the lattice. This is defined as:

$$W_n^{C^j} = S_n^j e^{-rt_w} N(d_1) - (X + C_n^{*j}) N(d_2) \tag{2.9}$$

where

$$d_1 = \frac{\ln(\frac{S_n^j}{X + C_n^{*j}}) - (r - 0.5v^2\sigma^2)t_w}{v\sigma\sqrt{t_w}} \tag{2.10}$$

[4]The case of a put option is similar.

and

$$d_2 = d_1 - v\sigma\sqrt{t_w} \qquad \textbf{(2.11)}$$

where t_w is the length of the wildcard period, $N(.)$ the cumulative unit normal density function, C'^{j}_{n} the wildcard-inclusive call option value at node j of step n which excludes the step n wildcard option, v the wildcard period volatility adjustment factor (described later) and σ the standard deviation of returns on the index.

Discussion

Quite apart from the general problems associated with the application of the binomial model to index option pricing (assumption of lognormal distribution of prices, the role of the futures contract in hedging and hence pricing of options on a spot index etc), the model has two problems associated with it:

i. the restriction of the number of timesteps, N, to the number of days remaining to expiry means that the pricing lattice used is coarse, especially on short-dated options, and this may induce an inaccuracy greater than that caused by the omission of the wildcard option;

ii. the wildcard value is highly sensitive to the estimate of v used in **(2.10)**. This point is crucial to the analysis contained in this chapter and is developed further in the following section.

The wildcard period volatility adjustment factor (v)

As with any option, the wildcard option value is a function of the volatility of the underlying asset. There is thus a need to incorporate an estimate of this volatility in **(2.10)**. Fleming and Whaley address this question by considering an adjustment to the annualised volatility used in wildcard-exclusive option pricing. Two extremes are considered. At the lower bound, the volatility observed in the wildcard interval is assumed to be the same (on a unit time basis) as the close to close volatility. In such a case, $v = 1$. At the other extreme, it is assumed that all the volatility occurs within the trading day, and that the volatility in the wildcard interval is the same as that observed in the trading day, again on a unit time basis. Since the length of the trading day of the S&P 500 index futures contract, which Fleming and Whaley use as the underlying asset in their empirical work, lasts 6¾ hours, this upper extreme value for v is $\sqrt{(24/6¾)}$ or approximately 1.9.

Fleming and Whaley determine the value of v empirically, by considering the **volatility ratios** of the wildcard interval and other parts of the day. The volatility ratio is defined as:

$$Volatility\ ratio = \sqrt{\frac{\sigma_w^2/0.25}{\sigma_i^2/hours}} \qquad \textbf{(2.12)}$$

where σ_w^2 is the variance during the wildcard period (divided by 0.25 because the length of the wildcard interval for the market during the period which they survey was ¼ hour), and σ_i^2 and *hours* the variance and length of time in hours of the *i*th interval (*i.e.* trading, overnight or close to close). Using data from a ten year history of the S&P 500 index futures contract, Fleming and Whaley [1994] determine an empirical estimate of the close to close volatility ratio of 1.6, which is used as the estimate of v in their empirical work.

The sensitivity of the Fleming and Whaley model to the value of v is shown in Figure 2 of their paper. This shows the average percentage of the wildcard-inclusive value of an option which can be attributed to the wildcard. The approximate values for 30 day at the money call and put options are detailed in Table 2.5 below.

v	**Calls**	**Puts**
1.0	1.6%	1.6%
1.6	2.9%	3.2%
1.9	3.8%	3.9%

Table 2.5. Mean value of wildcard feature as a percentage of the wildcard-inclusive option price for 30 day at the money OEX call and put options for different values of v, interpolated from Figure 2 of Fleming and Whaley [1994].

Table 2.5 shows that even a small change in the value of v makes a major change in the value of the wildcard feature.

Results

Fleming and Whaley use their model to compare wildcard-inclusive and wildcard-exclusive prices and thus attribute a value to the wildcard feature. It is a monotonically increasing function of time to expiry and the value is approximately the same for put and call options with identical moneyness and expiry characteristics. They value a 30 day at the money call option at about $7.04, of which approximately 2.9% is attributable to the wildcard feature. Making the assumption that such an option is representative of the entire range of OEX options traded in the course of a year and using the 1991 volume of 64,000,000 contracts traded, they calculate the aggregate value of the wildcard premiums embedded in these options as ($7.04 x 0.029 x 100 x 64,000,000) = $1.31 billion, or more than $5 million per trading day.

Appendix 2B: CHANGES IN THE INDEX LEVEL ACROSS THE WILDCARD INTERVAL IN 1992

Date	1610	Close	Change	Date	1610	Close	Change
01 July	2490.2	2493.4	0.1285%	08 September	2337.3	2337.7	0.0171%
02 July	2473.9	2476.1	0.0889%	09 September	2325.4	2327.5	0.0903%
03 July	2496.1	2497.1	0.0401%	10 September	2343.3	2340.6	-0.1152%
06 July	2470.1	2469.0	-0.0445%	11 September	2373.1	2370.9	-0.0927%
07 July	2493.8	2493.7	-0.0040%	14 September	2421.2	2422.1	0.0372%
08 July	2471.2	2472.6	0.0567%	15 September	2367.8	2370.0	0.0929%
09 July	2498.0	2497.9	-0.0040%	16 September	2369.5	2378.3	0.3714%
10 July	2490.0	2490.8	0.0321%	17 September	2486.7	2483.9	-0.1126%
13 July	2476.7	2478.3	0.0646%	18 September	2552.8	2567.0	0.5563%
14 July	2481.2	2484.0	0.1129%	21 September	2559.2	2560.1	0.0352%
15 July	2486.6	2486.4	-0.0081%	22 September	2586.4	2586.0	-0.0155%
16 July	2483.4	2483.4	0.0000%	23 September	2576.8	2580.5	0.1436%
17 July	2433.4	2431.9	-0.0616%	24 September	2611.2	2621.2	0.3830%
20 July	2403.4	2403.7	0.0125%	25 September	2604.8	2601.0	-0.1459%
21 July	2413.4	2415.6	0.0912%	28 September	2561.2	2560.0	-0.0468%
22 July	2388.7	2387.9	-0.0335%	29 September	2564.8	2565.5	0.0273%
23 July	2398.0	2399.5	0.0625%	30 September	2552.2	2553.0	0.0314%
24 July	2376.1	2377.2	0.0463%	01 October	2571.7	2572.3	0.0233%
27 July	2348.1	2348.0	-0.0043%	02 October	2545.1	2549.7	0.1807%
28 July	2369.5	2373.4	0.1646%	05 October	2448.2	2446.3	-0.0776%
29 July	2423.5	2423.2	-0.0124%	06 October	2485.5	2488.4	0.1167%
30 July	2412.3	2411.6	-0.0290%	07 October	2516.9	2517.1	0.0080%
31 July	2398.1	2399.6	0.0625%	08 October	2538.0	2538.8	0.0315%
03 August	2418.8	2420.2	0.0579%	09 October	2541.1	2541.2	0.0039%
04 August	2409.4	2407.5	-0.0789%	12 October	2558.6	2557.2	-0.0547%
05 August	2393.1	2392.8	-0.0125%	13 October	2587.4	2584.7	-0.1043%
06 August	2376.6	2377.6	0.0421%	14 October	2573.5	2574.7	0.0466%
07 August	2347.6	2350.1	0.1065%	15 October	2546.5	2546.6	0.0039%
10 August	2325.7	2325.7	0.0000%	16 October	2564.2	2563.9	-0.0117%
11 August	2308.1	2309.6	0.0650%	19 October	2563.1	2562.2	-0.0351%
12 August	2299.5	2303.1	0.1566%	20 October	2617.1	2617.0	-0.0038%
13 August	2318.3	2318.0	-0.0129%	21 October	2644.3	2645.7	0.0529%
14 August	2357.1	2356.8	-0.0127%	22 October	2659.5	2658.1	-0.0526%
17 August	2375.6	2376.1	0.0211%	23 October	2669.2	2669.7	0.0187%
18 August	2352.1	2354.7	0.1105%	26 October	2662.3	2661.6	-0.0263%
19 August	2364.2	2363.5	-0.0296%	27 October	2670.0	2669.8	-0.0075%
20 August	2359.4	2359.4	0.0000%	28 October	2651.3	2650.4	-0.0340%
21 August	2366.0	2365.7	-0.0127%	29 October	2642.3	2642.3	0.0000%
24 August	2308.3	2311.1	0.1213%	30 October	2658.7	2658.3	-0.0150%
25 August	2274.9	2281.0	0.2681%	02 November	2685.0	2687.8	0.1043%
26 August	2283.5	2285.0	0.0657%	03 November	2705.1	2705.6	0.0185%
27 August	2311.9	2311.6	-0.0130%	04 November	2693.0	2691.7	-0.0483%
28 August	2311.7	2312.6	0.0389%	05 November	2710.3	2711.1	0.0295%
01 September	2299.2	2298.4	-0.0348%	06 November	2703.3	2702.3	-0.0370%
02 September	2312.8	2313.0	0.0086%	09 November	2697.6	2695.4	-0.0816%
03 September	2384.3	2381.9	-0.1007%	10 November	2712.6	2714.6	0.0737%
04 September	2362.7	2362.2	-0.0212%	11 November	2696.8	2696.8	0.0000%
07 September	2371.5	2372.2	0.0295%	12 November	2727.9	2726.4	-0.0006%

Appendix 2C: INTRADAY FT-SE 100 INDEX RETURNS AND STANDARD DEVIATIONS IN 20 MINUTE INTERVALS DURING PERIOD 1 JULY 1992 TO 12 NOVEMBER 1992 INCLUSIVE

Interval	n	Mean (%)	Standard deviation (%)	Minimum (%)	Maximum (%)
08.30-08.50	96	-0.042	0.341	-1.215	1.508
08.50-09.10	96	-0.013	0.244	-0.535	1.048
09.10-09.30	96	-0.017	0.231	-1.199	0.629
09.30-09.50	96	0.013	0.217	-0.649	1.351
09.50-10.10	96	0.041	0.176	-0.321	1.001
10.10-10.30	96	0.007	0.161	-0.467	0.421
10.30-10.50	96	-0.012	0.158	-0.389	0.381
10.50-11.10	96	-0.035	0.208	-1.270	0.553
11.10-11.30	96	-0.003	0.111	-0.285	0.371
11.30-11.50	96	-0.001	0.158	-0.602	0.730
11.50-12.10	96	-0.003	0.129	-0.438	0.617
12.10-12.30	96	0.017	0.122	-0.500	0.414
12.30-12.50	96	0.015	0.121	-0.295	0.904
12.50-13.10	96	0.009	0.091	-0.444	0.291
13.10-13.30	96	-0.002	0.101	-0.633	0.285
13.30-13.50	96	-0.002	0.107	-0.416	0.366
13.50-14.10	96	-0.006	0.108	-0.508	0.299
14.10-14.30	96	-0.008	0.131	-0.454	0.405
14.30-14.50	96	-0.001	0.127	-0.279	0.881
14.50-15.10	96	-0.012	0.222	-0.524	1.605
15.10-15.30	96	-0.022	0.248	-0.987	0.827
15.30-15.50	96	0.023	0.145	-0.399	0.456
15.50-16.10	96	0.023	0.163	-0.454	0.527
16.10-16.30	96	0.030	0.102	-0.146	0.556

Chapter 3

RATIONAL EARLY EXERCISE WITH MARKET FRICTIONS

3.1 INTRODUCTION

The early exercise of options is an aspect of market efficiency on which little empirical research has been published. This chapter extends the well-documented theory of early exercise by taking into account the effect of market frictions. It is found that these make important alterations to rational investor behaviour. Rational behaviour is defined as those actions which are consistent with the efficient frontier in risk-return space; *i.e.* there exist no alternative actions which offer either increased returns for no increase in risk or the same return with a decrease in risk. Two types of irrational behaviour are identified: exercise when it is not rational to do so, which is called Type I behaviour in this chapter; and failure to exercise when this is rational, which is called Type II behaviour.

The key contribution of this chapter is that the method of settlement affects rational exercise practice. The frictions involved the in exercise of delivery-settled options motivate both holders and writers to close their positions through market transactions rather than exercise unless they wish to use exercise to adjust their medium- or long-term holdings of the underlying asset. In contrast, exercise of cash-settled options is exactly equivalent to a market sale, so that the motivation away from exercise towards market transactions is absent.

A set of testable hypotheses of rational practice is derived and compared with observed behaviour on the London Traded Options Market (LTOM)[1]. All but one of these hypotheses apply only to delivery-settled options. Broad conformity with these hypotheses is found, although differences in behaviour between holders of call options and holders of put options is observed.

[1]In 1992, LTOM was merged with the London International Financial Futures Exchange (LIFFE) and the joint market was renamed the London International Financial Futures and Options Exchange (also LIFFE). However, since the events in the present study occurred prior to that merger, the market is referred to as LTOM throughout this chapter.

Diz and Finucane [1994] undertake similar research on the exercise of S&P 100 index options. The present study differs from theirs in a number of respects. First, they examine only index options, whose exercise is settled in cash, whereas the present study examines both delivery-settled and cash-settled options. Next, the present study analyses a different market from them, one whose microstructure and frictions impose a markedly different rational strategy on both holders and, to a lesser extent, writers of options. Finally, their analysis is extended in the present study by deriving and testing a set of hypotheses of rational exercise practice for option holders.

The chapter is organised as follows: in Section 3.2, the arrangements for exercise on LTOM are described, and their effect on rational exercise practice considered. The theoretical background to early exercise is then presented in Section 3.3, followed in Section 3.4 by the derivation of a set of testable hypotheses, the methodology adopted for testing them and a description of the sample used in the analysis. Section 3.5 presents the results of the analysis. Section 3.6 concludes.

3.2 EXERCISE ARRANGEMENTS ON THE LONDON TRADED OPTIONS MARKET

Option holders who wish to exercise early notify their intentions to the London Options Clearing House (LOCH) via their broker before 16.31 on any permitted exercise day. The LOCH computer selects at random one or more counterparties with an aggregate equivalent short position in the options and the appropriate exercise notices are issued. Once exercise notices have been issued, recipients are unable to close their short positions by buying back options in the market; they are obliged to fulfil the terms of the exercise notice.

Exercise of options is by one of two methods, depending on the underlying asset. For FT-SE 100 index options, settlement is by cash, to take place by 10.00 the following day, with the settlement price fixed at the 16.10 index level. Settlement of the individual equity options is undertaken by transfer of stock through the London Stock Exchange account system[2].

The account system is based on a series of (usually) fortnightly periods. All equity transactions within these account periods are settled ten days after the end of the account. Writers of call (put) option contracts on an individual stock which are exercised are deemed to have sold (bought) the specified shares on the day after the exercise notice is issued and settlement is due on the corresponding account day.

Writers who have an uncovered call option exercised against them, are thus required to buy the contracted shares before the end of the account. If writers of put options have no wish to retain the shares delivered to them through exercise, it is helpful for them to be able to sell the shares in the market before the end of the account. Accordingly, there needs to remain an interval between exercise and the end of the account. For this reason, LTOM rules prevent the exercise of individual equity options on the last day of an account. FT-SE 100 index options, which are settled for cash the following business day, may be exercised on any business day.

[2]On 18 July 1994, the account system was abandoned by the London Stock Exchange in favour of a ten day rolling settlement system. Appendix 3A discusses the implications of this for the hypotheses derived and presented in this chapter.

The distinction between the two settlement methods has some significance in determining rational exercise practice, because they have different effects on the risk of the option holders' portfolios. To illustrate this, consider two investors A and B. Each has an identical long position in a portfolio of stocks replicating the FT-SE 100 index. However, investor A has hedged this position with a portfolio of put options on each individual stock held long, whereas investor B has hedged the position by an index put option. Assume the market falls to such an extent that investor A's stock options and investor B's index options are rationally exercised. Investor A is left with cash, but no exposure to the market, whereas investor B, whilst receiving cash from the exercise of the index put options, still retains the exposure of the portfolio to the market. If investor A wishes to retain exposure to the market, he is obliged to undertake a further transaction to achieve such exposure. Alternatively, he could have chosen not to exercise the options, but to sell them in the market and retain the stocks. Investor B, by contrast, retains exposure to the market: if she wishes to shed this, she is forced to undertake a further sale of her stock portfolio.

Thus exercise of cash-settled options is exactly equivalent to a sale of the options position in the market, except that market sale is available to options holders from 08.35 until just after 16.10, whereas the opportunity to capture a given settlement price is available only between 16.10 and 16.31. Settlement of the sale of an index option position and its exercise are both due at 10.00 the following day, so the cashflow implications are also identical. By contrast, exercise of delivery-settled options is analogous to a sale of the option in the market together with a transaction in the underlying stocks.

There is one further distinction between the two settlement methods. Holders of index options have what is known as a 'wildcard' option. This arises from the fact that the settlement price for the day is determined at 16.10, whereas holders have up to 16.31 to decide whether or not to exercise. The arrival of price sensitive information during this interval will not affect the proceeds of exercise but will affect the next tradeable price of the option and thus may induce the option holder to change the decision which was dictated by market circumstances at 16.10. This wildcard option does not apply to holders of delivery-settled options, since the cash value of the asset transferred by exercise is not fixed at a moment in time. The wildcard option is examined in detail in Chapter 2 and the extent of its influence on the database used in the present study is considered in Section 3.5.

3.3 THE IMPACT OF MARKET FRICTIONS ON EARLY EXERCISE THEORY

Theoretical background without frictions

The theory of early exercise in frictionless markets is quite straightforward. Merton [1973] shows that it is never rational to exercise early an American call option on a stock which does not pay a dividend. Where dividends are paid, early exercise may be rational: early exercise offers investors the present value of the dividend stream over the remaining life of the option, ΣD, but they forego the benefit of deferral of the exercise price payment, a penalty of $X(1 - e^{-r\tau})$, where X represents the exercise price, r, the riskfree rate of interest and τ, the time to expiry of the option. Thus $\Sigma D \geq X(1 - e^{-r\tau})$ is a boundary condition for early exercise of a call option.

Roll [1977] shows that there exists some finite value of the underlying asset price, S, referred to as S^*_{call}, above which early exercise is rational in order to capture a dividend. A similar argument (developed in, *inter alia*, Cox and Rubinstein [1985]) applies to put options. There exists some finite value, S^*_{put}, below which early exercise of put options is rational. The unsubscripted term, S^*, is used to refer jointly to the two threshold prices S^*_{call} and S^*_{put}.

Option holders have the choice between holding the option open (a 'live' option) or closing their position by exercise (a 'dead' option). The dead option is worth $S - X$ for calls and $X - S$ for puts, where S is the value of the underlying stock or index. Using conventional option pricing models (*e.g.* Cox, Ross and Rubinstein [1985]), the live call option is worth $C(S, X, \tau, \sigma, r, \Sigma D)$ and the live put option is worth $P(S, X, \tau, \sigma, r, \Sigma D)$, where σ is the volatility of the underlying stock or index and the other parameters as defined earlier. In the absence of transactions costs, the rational option holder will exercise only if $C(S, X, \tau, \sigma, r, \Sigma D) \leq S - X$ or $P(S, X, \tau, \sigma, r, \Sigma D) \leq X - S$.

S^*_{call} represents that value of S for which, holding all other parameters constant, $C = S - X$. Similarly, for put options, S^*_{put} represents that value of S for which $P = X - S$. The values of S^*_{call} and S^*_{put} will thus be functions of the standard option valuation parameters, X, τ, σ, r and ΣD. Table 3.1 shows the sign of the change in S^*_{call} and S^*_{put} with a positive change in each of these parameters.

Factor	**Calls (*C*)**	**Puts (*P*)**
Exercise price (*X*)	+ve	+ve
Time to expiry (τ)	+ve	-ve
Volatility (σ)	+ve	-ve
Interest rate (*r*)	+ve	+ve
Dividend stream (ΣD)	-ve	-ve

Table 3.1: The relationship between S^* and the different option valuation factors

The impact of market frictions

Market frictions have an influence on the theory outlined above. Four frictions are considered:

i. Direct transactions costs

ii. The bid-ask spread on the underlying asset

iii. The bid-ask spread on the option

iv. Differential interest rates

i. *Direct transactions costs*

Holders of options face direct transactions costs in closing out their positions. For individual equity options, which are settled by delivery, closing the position by sale or purchase in the market incurs a brokerage commission whereas exercise incurs a larger brokerage commission, a clearing house charge and possibly a second brokerage commission for disposal of the acquired shares or reacquisition of the shares disposed of. For index options, which are settled by cash, the position is different: tariffs vary according to the investor's broker, but there is generally little or no difference between the direct transactions costs of exercise and those of a sale of the position in the market.

Thus, for individual equity options, the option holder incurs lower direct transactions charges in a sale of the option than in its exercise (still more so if the exercise requires another transaction cost for retrading the shares transferred in the exercise process). However, where exercise is rational, the option is *ipso facto* worth more dead than alive, which implies an absence of counterparties willing to buy the option from the existing holder.

Nevertheless, two sources of willing counterparties do exist. The first is the set of option writers Any of these who have options exercised against them face direct transactions charges similar to those described above and thus will generally find it cheaper to buy back their short positions than to face exercise. The second source of willing counterparties are the marketmakers. They generally face the cheapest direct transactions costs and are required to offer a two-way price in all open series. The purchase and exercise of an option, together with the disposal or reacquisition of the shares transferred in the exercise process, exposes a marketmaker to an inventory risk which lasts only for the duration of the transaction process, which can be completed in less than a minute. Therefore marketmaker competition should ensure that they bid fractionally short of their breakeven point (after transactions charges) for buying the option and exercising it.

Hence, even where $S \geq S^*_{call}$ or $S \leq S^*_{put}$, exercise of delivery-settled options should be undertaken only by and against those investors who wish to use their options positions to make permanent or semi-permanent changes in their inventory of the underlying asset. Other investors will close out their positions by trading with their counterparties. Any remaining mismatch will be absorbed by marketmakers, who face the lowest costs of exercise. In contrast, the impact of direct transactions charges makes no difference to the behaviour of holders of cash-settled options, since the charges are the same whether the holder exercises or sells in the market.

ii. The bid-ask spread on the underlying asset

Holders or writers of options on individual stocks who do not need or want to hold their revised stock positions upon exercise will need to trade again in the stock upon exercise. The bid-ask spread on the stock is an extra charge and hence will make it still cheaper for holders and writers to close their positions through a market transaction rather than through exercise. Once again, this does not apply to holders and writers of cash-settled options, since there is no transaction in the underlying asset on exercise.

iii. The bid-ask spread on the options

With all other frictions assumed away, the bid-ask spread on the options will motivate holders to exercise rather than to sell in the market. Consider an option for which early exercise is rational: *i.e.* $S > S^*_{call}$, or $S < S^*_{put}$. The investor faces the choice between selling in the market or exercising. However, whereas early exercise will yield $S - X$ for calls or $X - S$ for puts, the investor must expect to have to reward any counterparty who offers to buy the option in the marketplace. Since the option is rationally exercisable, this counterparty cannot value the option at more than $S - X$ or $X - S$ respectively and therefore will bid below these values to ensure a turn on the trade. Hence, under the assumption of no other frictions, exercise will yield $S - X$ or $X - S$, whereas market sale will yield $S - X - \xi$ or $X - S - \xi$, where ξ represents the counterparty's turn on the transaction. Thus exercise appears a more productive choice than market sale.

Nevertheless, relaxation of the assumption of no other frictions changes the position. As shown above, the size of commission charges and the bid-ask spread on the underlying stock motivate holders and writers of rationally exercised delivery-settled options to trade in the market rather than to exercise unless they wish to use the exercise process to undertake a medium- or long-term change in their stock portfolios.

If holders and writers of options can cut out the marketmakers by trading directly with each other, for instance through use of the public limit board, this friction of the bid-ask spread on the option can be eliminated, thus maintaining the motivation to close positions through market trading rather than through exercise. This is not the case for index options: given that the direct transactions charges for sale and exercise are generally the same, the bid-ask spread on the option will motivate holders of index options to exercise (which avoids the spread) rather than to sell in the market.

Thus for rationally exercised delivery-settled options, it is argued that a sale in the marketplace is a superior strategy to early exercise except where the option holders wish to make a permanent or semi-permanent change in their inventory.

iv. *Differential interest rates*

Option pricing models are generally derived from the concept that the returns from an option can be replicated by an appropriately levered position in the underlying stock. The assumption is normally made that investors can borrow and lend at the riskfree rate. For institutional investors, this is sufficiently close to reality to be reasonable. For private investors, however, the assumption is by no means valid. They face a significant premium over the riskfree rate on their borrowing and a significant discount (after taxation) on their lending.

Private investors will therefore be less willing than institutional investors to exercise early, because they will value the remaining option more highly. In accordance with the relationships shown in Table 3.1, the private investor holding call (put) options will perceive a higher (lower) critical value S^* than the institutional investor.

For UK private investors in the summer of 1991, midway through the period under analysis in this study, the post-tax interest rate differential between saving and borrowing was of the order of 8% symmetrically across a riskfree rate of 12%. Tests of the effect of this on a subsample of the observations in this paper show that the heterogeneity of interest rates faced by investors on LTOM is likely to have only a very marginal effect on rational exercise practice. The critical value S^* will vary by something of the order of 1%, so the theory applying in frictionless markets will be affected only very marginally by the existence of differential interest rates.

3.4 HYPOTHESES, DATABASE AND METHODOLOGY

From the preceding description of theory, frictions and the institutional arrangements on LTOM, the following five testable hypotheses are derived. They are all applicable to delivery-settled options, but, as argued in the respective rationales, only hypothesis *a.* applies to cash-settled options.

a. *Holders of options will not exercise where the market bid price of the option exceeds $S - X$ for call options and $X - S$ for put options.*

Rationale:

$S - X$ and $X - S$ represent the proceeds of exercise for calls and puts respectively. If the market bid price exceeds these values, greater value is obtained through closing the position through a market sale than through exercise. This hypothesis applies to holders of both cash-settled and delivery-settled options.

b. *Holders of call options will not exercise early except in the account immediately prior to an ex-dividend event and then only if* $\Sigma\,\alpha D \geq X(1-e^{-r\tau})$.

Rationale:

This follows from Merton [1973]. It should be noted that some investors are liable to tax on the dividend capture achieved through exercise under this condition and, in such cases, ΣD, which was described above in a frictionless context, has been replaced by $\Sigma\,\alpha D$, where α = (1-tax rate). However, for the purposes of this study, the position of a tax-exempt investor (*i.e.* $\alpha = 1$) is considered, since irrational behaviour for a tax-exempt investor under this hypothesis will also be irrational for a tax-paying investor.

Whilst this hypothesis is directly applicable to delivery-settled options, it applies only indirectly to cash-settled options. As they approach the point at which they become exercisable, either through dividend capture or expiry, the market bid price will fall below the proceeds of exercise, since any marketmakers purchasing the options in these circumstances will wish to ensure a turn on the trade and will therefore bid below the proceeds of exercise. Since the consequences and transactions costs of exercise of index options are the same as their sale, holders of such options will be motivated to exercise rather than to sell. Hence this hypothesis becomes a subset of hypothesis *a.* for cash-settled options.

c. *Where exercise of a given equity options series occurs, all other options of the same class with the same or shorter expiry dates and the same or further in the money exercise prices will also be exercised.*

Rationale:

Exercise implies that the holder regards the option as more valuable dead than alive. Since the options of a given series are homogeneous, it is irrational for the holder to differentiate between them. If holders of delivery-settled options do not wish to adjust their equity inventory to the full extent of their options positions, they should sell the remainder in the market.

Table 3.1 above shows the sign of the relationship between a change in the different option valuation factors and the change in S^*. It is seen from this that a shorter expiry date will decrease S^*_{call} and increase S^*_{put}. A similar argument applies to exercise prices. A decrease in a call exercise price (hence further in the money) similarly reduces the value of S^*_{call} and an increase in a put exercise price (hence again further in the money) increases S^*_{put}.

Since S^*_{call} and S^*_{put} represent respectively the minimum and maximum values of S which make exercise rational, any respective decrease or increase in their value by shorter expiry dates or further in the money exercise prices must also make exercise rational: option holders who do not wish to use exercise to alter their portfolios should sell in the market.

Note that this hypothesis does not apply to cash-settled options, since, as shown above, exercise is equivalent to a sale and a sale of a part of an option position can be rational at any time.

d. *Exercise of delivery-settled options will occur only on the penultimate day of the account*

Rationale:

A decision to exercise early in the account cannot be reversed, offers no benefit to options holders and exposes them to the risk of adverse information arriving during the remainder of the account. The penultimate, rather than the final, day of an account is specified because LTOM rules do not permit exercise of delivery-settled options on the final day of an account. This does not apply to cash-settled options, since these are settled the following business day, outside the account system.

e. *In the account in which exercise becomes rational, the quoted bid-ask spread for delivery-settled options will narrow.*

Rationale:

As shown above, holders and writers of rationally exercised delivery-settled options have a mutual interest in closing their positions through market trades rather than through exercise, in order to minimise direct transactions costs. The achievement of conditions for rational exercise, $S > S^{*}_{call}$ and $S < S^{*}_{put}$ will trigger a simultaneous supply of both willing buyers and willing sellers of options positions, so the marketmakers' role is reduced from being a major supplier of liquidity to the absorption of any remaining mismatch between buyers and sellers. Such a role is virtually riskless, since they are able to exercise immediately at the lowest transactions costs: therefore the reward to which they are entitled is reduced from normal. Retail investors may post limit orders, a mechanism which enables holders and writers of options to trade directly with each other and to cut out the marketmaker.

Once again, this hypothesis does not apply to cash-settled options, since exercise will enable holders and writers to avoid the bid-ask spread with no increase in direct transactions costs.

The database

The database used in this study consists of daily records from LOCH over a 229 trading day period from 16 January 1991 to 9 December 1991 inclusive. For each option series traded on LTOM, the records show the open interest on the preceding and current days, the number of contracts traded and exercised on the day, the closing mid-price of the underlying asset, the closing bid and ask quotes for the option series, the high and low transactions prices both for the day and for the history of the option series and the date of the last trade. A sample record is shown in Appendix 3B.

From these records, a database is constructed of each early exercise event. An event is defined as an entry in the 'exercise' column of the daily records occurring prior to option expiry. A single observed event will comprise the decisions of one or more investors: the records show how many contracts of a given series are exercised, but not how many holders choose to make the exercise decision.

The numbers of early exercise events and contracts exercised observed for both stock and index options are shown in Table 3.2 below:

	Stock options		Index options	
	Exercise events	**Contracts exercised**	**Exercise events**	**Contracts exercised**
Calls	661	129,806	172	14,787
Puts	943	152,653	223	17,359
Total	1,604	282,459	395	32,146

Table 3.2: Breakdown of database used in the study

Dividend and bid-ask spread information on the underlying stocks is taken from the London Stock Exchange and the interest rate used is the daily closing 3 month London Interbank Offered Rate (LIBOR) as reported on Datastream.

Methodology

Each of the hypotheses *a* to *e.* above is tested for the stock options sample. As mentioned above, only hypothesis *a.* applies to the index options, since these are settled by cash rather than delivery. Hypothesis *a.* entails a simple comparison of the closing bid price of the options series and $S - X$ or $X - S$ for call and put options respectively. For stock options, the analysis first uses the mid-price of S, and then adjusts for half the bid-ask spread on the underlying stock. For index options, the analysis adjusts for the impact of the wildcard option. Hypothesis *b.* is tested first by establishing whether or not exercise takes place in the account period immediately preceding an ex-dividend event and then by comparing the present value of the dividend stream with $X(1-e^{-r\tau})$.

Hypothesis *c.* entails analysis of the open interest in the relevant options series. Hypothesis *d.* is tested by a statistical comparison of the volume of exercise taking place on the penultimate day of an account with the volumes on other days.

Finally, hypothesis *e.* is tested in the following manner. First, all observations of events in which exercise is demonstrably irrational under the previous criteria are eliminated. For the remaining observations, the quoted bid-ask spread on the day of exercise is compared with the quoted spread on the equivalent day of the preceding account. This test is concerned with the change in the spread between the account preceding observed exercise, $t - 1$, and the time of the observed exercise, t. The change in the absolute spread, ΔQ, is defined as:

$$\Delta Q = (P_t^{MA} - P_t^{MB}) - (P_{t-1}^{MA} - P_{t-1}^{MB}) \qquad \textbf{(3.1)}$$

where P_t^{MA} and P_t^{MB} are the closing option ask and bid prices respectively prevailing on the day of observation, t, and P_{t-1}^{MA} and P_{t-1}^{MB} are the closing prices prevailing on the equivalent day of the preceding account.

The test of an absolute rather a proportional measure of the spread is used because casual observation of the market shows that the absolute spread is generally a positive function of the option value and the proportional spread is generally a negative function. The database analysed in this study comprises observations of options which (in the option holders' view) were rationally exercisable in the account under observation (time t), but were not rationally exercisable at the equivalent point in the preceding account (time $t-1$). Thus, although there is ample scope for exceptions, intuition suggests that the options will have become more valuable between time $t-1$ and time t. This intuition is tested by analysis of the change in the mid price of the observed options (ΔP^{mid}), defined as:

$$\Delta P^{mid} = 0.5(P_t^{MA} + P_t^{MB}) - 0.5(P_{t-1}^{MA} + P_{t-1}^{MB}) \qquad \textbf{(3.2)}$$

Therefore, there is an expectation that, in the absence of the forces described in this hypothesis, the absolute spread will widen between the two observation points and the proportionate spread will narrow. However, it is hypothesised that the countervailing forces of a simultaneous increase in the supply of and demand for the options will act to narrow both the absolute and proportional spreads. Thus, isolation of this effect requires analysis of the absolute spread.

t tests of the mean values of ΔQ and ΔP^{mid} are undertaken. Significantly negative values of ΔQ indicate that the spread has narrowed and significantly positive values indicate that the spread has widened. Significantly positive values of ΔP^{mid} lend support to the intuition that options rationally exercised at time t are more valuable than in the preceding account (time $t-1$).

3.5 RESULTS

a. Holders of options will not exercise where the market bid price of the option exceeds S - X for call options and X - S for put options.

Violation of this hypothesis will indicate Type I irrational behaviour. The results are presented in Table 3.3 below.

	Exercise events	% of sample	Contracts exercised	% of sample	Value (£)
STOCK OPTIONS					
Calls	29	4.38	5,089	3.93	59,900
Puts	53	5.62	7,458	4.89	104,915
Total	82	5.11	12,547	4.44	164,815
INDEX OPTIONS					
Calls	12	6.98	206	1.39	4,730
Puts	6	2.69	407	2.34	19,160
Total	18	4.56	613	1.91	23,890

Table 3.3: Number of violations of hypothesis *a.* before allowing for the bid-ask spread on the underlying stock and the wildcard option on index options

Table 3.3 shows a small incidence of violation of hypothesis *a*. For stock options, 82 violations are observed, representing 5.11% of the total stock options sample. These violations represent 12,547 contracts exercised (4.44% of the total). 18 violations are observed for index options (4.56% of the total) representing 613 contracts exercised (1.91%). Table 3.3 appears to indicate a certain degree of market inefficiency. However, there are two mitigating factors: one for stock options and one for index options. For stock options, the choice between exercising early and selling the option in the marketplace needs to take account of the bid-ask spread on the underlying stock. The value of S used in Table 3.3 is the mid-price, whereas holders of a call (put) option who sold the option and traded the stock in the market would buy (sell) the stock at the ask (bid) price. Table 3.3a shows the number of violations observed for stock options after adjusting S for one half of the bid-ask spread on the underlying stock.

	Exercise events	% of sample	Contracts exercised	% of sample	Value (£)
Calls	10	1.51	137	0.11	6,510
Puts	14	1.48	1,469	0.97	31,565
Total	24	1.50	1,606	0.57	38,075

Table 3.3a: Number of violations of hypothesis *a*. for stock options after allowing for the bid-ask spread on the underlying stock

Table 3.3a shows only a small level of irrational behaviour - less than 1% of all contracts exercised in the sample period - but it is surprising that it exists at all. The holder of an option has to make a conscious decision to exercise and it ought to be a necessary part of the decision process to consider *both* alternatives to exercise; *i.e.* selling in the market and holding the option.

A marked distinction between put and call exercise is seen in Table 3.3a: the average number of contracts exercised per observed violation is less than 14 for call options, but more than 100 for put options. Since each contract is for 1,000 shares, the average put option exercise event in Table 3.3a accounts for more than 100,000 shares. It may be that the option holders chose to exercise rather than sell both the stock and the options in order to minimise the market impact of the transaction. The stocks on which options are listed are all very liquid, and the market would not have much difficulty in absorbing a sell order for 100,000 shares, but the options are rather less liquid and it could be that the option holders believed that a large sell order would not be accommodated at the prevailing market bid price.

The prices considered in the analysis are closing prices. Using intraday prices would make no difference to the analysis. The exercise decision should be made at the end of the day; choosing to exercise in the middle of the day exposes the option holder to a small amount of unrewarded inventory risk, similar to the decision to exercise before the end of an account.

The mitigating factor for index options is the so-called 'wildcard' option. A detailed analysis of this is presented in Chapter 2 of this thesis. At this stage, consider the following example, taken from the database. At 16.10 on 21 March 1991, the settlement value of the index was 2477. The bid price of March 2200 Calls was 278. Hence exercise would be irrational under hypothesis *a.*, since the option holder who wished to close the position would obtain 1 point (£10) more per contract through market sale than through exercise. However, during the wildcard interval, the index fell by 2.2 points and, assuming an option delta of 1, the next expected bid price of the option would fall by the same amount, to 276 (allowing for a minimum price movement of ½). Rather than face this fall, the option holder decides to exercise and take 277 points for the position. Thus an apparently irrational decision can be found to be rational by the wildcard option.

This line of reasoning is used on each of the 18 instances of index option violation observed in Table 3.3. In fact, it serves to rationalise only two violations, both call options, accounting for 56 contracts and a value of £620. Table 3.3b below shows the incidence violation of hypothesis *a.* for index options after allowing for exercise of the wildcard option.

	Exercise events	% of sample	Contracts exercised	% of sample	Value (£)
Calls	10	5.81	150	1.01	4,110
Puts	6	2.69	407	2.34	19,160
Total	16	4.05	557	1.73	23,270

Table 3.3b: Number of violations of hypothesis *a.* for index options after allowing for exercise of the wildcard option

b. *Holders of call options on individual stocks will not exercise early except in the account immediately prior to an ex-dividend event and then only if* $\Sigma\, \alpha D \geq X(1-e^{-r\tau})$.

Hypothesis *b.* is tested in two stages: first to check conformity with the timing element and then to check conformity with the dividend condition. Table 3.4 below analyses the timing condition.

	Exercise events	%	Contracts exercised	%
Total observations	661	100.0	129,806	100.0
Exercised during dividend capture account	323	48.9	74,583	57.5
Exercised during expiry account	282	42.7	44,207	34.1
Exercised outside expiry/dividend capture accounts	56	8.5	11,016	8.5

Table 3.4: Timing of early exercise of call options

Table 3.4 shows limited violation of the timing condition. 323 exercise events are to capture a dividend and these account for 57.5% of the call option contracts exercised during the sample period. A further 34.1% of the sample represents early exercise during the expiry account of the option. This is irrational since such premature exercise offers no gain and deprives the investor of the ability to benefit from any information which arrives after they have made the exercise decision. By delaying exercise until expiry, the investor loses nothing and gains the benefit of the full information flow. These observations of early exercise during the expiry account have a mean time to expiry of 7.38 days.

The 56 exercise events (11,016 contracts exercised - 8.5% of the total sample) occurring outside the ex-dividend or expiry accounts show Type 1 irrational behaviour. Given transactions costs, it is assumed that the investor's objective is to obtain more of the underlying stock for the portfolio. In such circumstances, rational behaviour is to wait until an ex-dividend event or expiry. Not only would payment of the exercise price be deferred, but some protection would also be gained against an unfavourable movement in the underlying share price. The mean time to expiry or the next ex-dividend event for these options is 31 days.

Having identified 323 exercise events (74,583 contracts) observed during the account period prior to an ex-dividend event, the second element of hypothesis *b.* remains to be tested, namely conformity with the dividend condition. These events will be irrational unless $\Sigma\, \alpha D \geq X(1 - e^{-r\tau})$. For these observations, all variables are observable except α. The strictest test is to consider the case of the tax exempt investor and assume an α value of 1 and a value for D of the *gross* dividend payments. If $\Sigma\, \alpha D < X(1-e^{-r\tau})$ on this definition, exercise cannot be rational for any investor. Whilst the condition embraces the possibility of a dividend *stream*, in all 323 exercise events, there was only a single dividend payment remaining prior to expiry.

23 exercise events violating this condition are observed (993 contracts exercised - 0.76% of the total sample). The economic value of these violations is generally very small. The total value is £18,429, of which £10,877 is accounted for by a single exercise event consisting of 88 contracts exercised.

In summary, therefore, hypothesis *b.* is fulfilled to a large extent. 56 (8.5%) exercise events occur outside the dividend capture or expiry account. Of the 323 exercise events occurring during the dividend capture account, 23 (7.1%) are irrational on the basis that the present value of the dividend stream captured is less than the value of deferring payment of the exercise price. The number of contracts exercised in these 23 violations represents 0.76% of the call options sample.

c. *Where exercise of a given equity options series occurs, all other options of the same class with the same or shorter expiry dates and the same or further in the money exercise prices will also be exercised.*

Multiple exercise events during the same account are filtered. Accordingly, where there are several observations of exercise of a given options series during an account, only the last observation is used. This filtering reduces the number of exercise events to 1,328 (230,799 contracts exercised) comprising 490 calls (96,074 contracts) and 838 puts (134,725 contracts). The statistic tested is q, defined as:

$$q = \frac{\text{number of contracts exercised}}{\text{number of contracts exercised} + \text{remaining open interest}} \tag{3.3}$$

Remaining open interest is defined as the open interest of all options of the same class as the series observed with the same or shorter expiry dates and the same or further in the money exercise prices. According to hypothesis *c.*, q should equal 1 in all cases. Table 3.5 gives a summary of the findings:

	Exercise events	Mean value of q	No. of cases where $q = 1$	%
Calls	490	0.502	104	21.2
Puts	838	0.685	325	38.8
Total	1,329	0.618	429	32.3

Table 3.5: Proportion of open interest exercised simultaneously

Table 3.5 shows considerable violation of the hypothesis and a significant (1%) difference between the means of the put and the call option subsamples. The mean value of q is 0.618 rather than 1 and the proportion of cases where $q = 1$ is 32.3% rather than 100%. It is possible that these results are affected by the irrational behaviour of a small number of small investors committing either Type I or Type II irrational behaviour. Either action will have the effect of reducing both the mean value of q and the percentage of observations where $q = 1$.

To allow for this, two modifications to the test are made. First, all exercise events in which $q < 0.05$ are eliminated. In this way, those observations of exercise by a very small proportion of the open interest (which is likely to be Type I irrational behaviour) are discounted. Second, the criterion of conformity to the expectation is changed to $q > 0.95$. In this way, observations of failure to exercise by a very small proportion of the open interest (Type II irrational behaviour) are discounted. The results of this modified test are shown in Table 3.5a.

	Exercise events	Mean value of q	No. of instances where $q > 0.95$	%
Calls	418	0.585	132	31.6
Puts	794	0.722	376	42.4
Total	1,212	0.675	508	41.9

Table 3.5a: Proportion of open interest exercised simultaneously (modified test)

Therefore, even after discounting irrational behaviour on the part of a small number of small investors, there remains a considerable violation of the hypothesis and a significant (1%) difference between the call and put subsamples. Tables 3.5 and 3.5a show a lack of unanimity among investors over optimal exercise timing and this is greater for call options than for put options.

The results in Table 3.5a could be attributed either to investors exercising where it is irrational to do so, or to investors failing to undertake a rational exercise. The fact that the mean values of q are greater than 0.5 lends support to the idea that the latter is the case, reinforced by the fact that earlier tests have shown little incidence of exercise where this is irrational. However, proving that failure to exercise is irrational is not easy. Hypothesis *c.* is predicated on an assumption that all option holders have an identical estimation of the volatility of the underlying asset. It was shown above that where there is a heterogeneous estimation of this, there will be a heterogeneous estimation of the critical value S^*, and hence heterogeneous exercise practice.

The results in Tables 3.5 and 3.5a could therefore still be rationalised by assuming heterogeneous option valuation among holders. This rationalisation can be tested. If correct, q would be a positive function of the degree to which the options series is in the money. The deeper in the money the option, the greater is the threshold value of σ which calls for option retention rather than exercise. The test is therefore to measure the correlation between q (the proportion of the open interest exercised) and a statistic m which measures the extent to which the option is in the money. m is defined as $100(S/X - 1)$ for calls and $100(1 - S/X)$ for puts. A significant (1%) positive relationship *is* found, both for calls and puts, but the explanatory power of this relationship is very small (R^2 = 3.1% and 1.1% respectively). It is therefore concluded that many options were not exercised when it was rational to do so.

d. Exercise of delivery-settled options will occur only on the penultimate day of an account

An analysis of both call and put options is presented in Table 3.6 below.

	Exercise events				Contracts exercised			
	On penultimate day	**%**	**Before penultimate day**	**%**	**On penultimate day**	**%**	**Before penultimate day**	**%**
Calls	287	43.4	374	56.6	73,499	56.6	56,307	43.4
Puts	809	85.8	134	14.2	138,945	91.0	13,708	9.0
Total	1,096	68.3	508	31.7	212,444	73.7	75,825	26.3

Table 3.6: Breakdown of timing of exercise within account periods

Table 3.6 shows a marked difference between put and call options. Put option holders generally conform with the hypothesis that exercise will take place on the penultimate day of an account. 85.8% of all exercise events and 91% of contracts exercised during the sample period comply with this hypothesis. There is much greater deviation from the hypothesis with call option holders: only 43.4% of exercise events and 56.6% of contracts exercised comply. This has implications for options *writers*, since it was shown earlier that the impact of direct transactions costs will motivate options writers to close their positions through purchase in the market rather than allowing themselves to be exercised against unless they wish to use the occasion of exercise to make a permanent or semi-permanent change in their portfolios. The inference from Table 3.6 is that they should undertake the market purchase early in the account in which exercise becomes rational, because, particularly in the case of call options, there is a real risk of being exercised against prematurely in the account.

For those options which are exercised prematurely within an account, the mean value of the interval between exercise and the penultimate day of the account is 7 days, for both calls and puts.

e. *In the account in which early exercise becomes rational, the quoted bid-ask spread for the option will narrow.*

The absolute quoted bid-ask spread is compared with the spread quoted on the same series on the equivalent day in the preceding account. After further elimination of series for which there is no quotation in the preceding account, 1,464 exercise events remain. Two measures are tested: the change in the absolute size of the bid-ask spread, ΔQ, and the change in the mid-price of the options, ΔP^{mid}. The results are presented in Table 3.7 below.

	Exercise events	Contracts exercised	ΔP^{mid}	*t*	ΔQ	*t*
Calls	641	121,066	14.14	*12.65*	-0.1708	*-3.62*
Puts	823	135,579	7.08	*12.12*	0.1233	*3.03*
Total	1,464	256,645	10.17	*17.06*	-0.0055	*-0.18*

Table 3.7: Mean changes in mid-price and quoted spread of exercised options between account preceding exercise and account during which exercise occurs

Table 3.7 shows, as expected, that, for options which are exercised, the mid-price increases significantly between the preceding account and the account in which exercise occurs. The increase is twice as large for call options (14.14) as for puts (7.08). However, the contraction in the absolute size of the spread, which was hypothesised for both classes of option, is seen only for calls. This is surprising for two reasons: first, because the hypothesis did not distinguish between calls and puts, second, because the countervailing force, namely the tendency for the absolute size of the spread to widen with the mid-price of the option, is seen to be greater for calls than for puts, which should make the detection of spread contraction more difficult.

The resolution may lie in a clientele effect. The hypothesised contraction of spreads occurs because direct transactions costs create a mutuality of interests for both option holders and option writers to close their positions in rationally exercised options through market transactions rather than through exercise, unless they wish to use exercise to effect a permanent or semi-permanent change in their portfolios. Writers of put options who wish to hedge their positions, need to be able to sell the underlying asset short. Figlewski and Webb [1990] argue that many investors face short selling constraints, and that one of the roles of an options marketmaker is to help complete the market by filling the gap in the supply of put options. This reasoning implies that marketmakers form a large proportion of the writers of put options, and this will lessen the mutuality of interest between option writers and option holders. Marketmakers, facing the lowest costs of exercise and knowing that option holders are motivated to close through market sale rather than through exercise, have no incentive to narrow the quoted spread.

3.6 CONCLUSION

The standard theory of early exercise needs modification in the light of market frictions and institutional arrangements. In particular, the scale of direct transactions costs makes it cheaper for holders and writers of delivery-settled options to close out their positions by selling or buying back their positions in the options marketplace, rather than exercising or facing exercise. Exercise should be restricted to investors who wish to use their options positions to make a permanent or semi-permanent change to their inventory of the underlying asset. In contrast, for cash-settled options, market frictions serve to encourage exercise rather than sale, since the direct transactions costs are the same and the bid-ask spread is avoided in exercise.

Two types of irrational behaviour may be distinguished: Type I is exercise where it is not rational to do so and Type II is failure to exercise where this appears rational. Type II is more difficult to establish, since in most instances, the holder of the option can justify failure to exercise by a higher personal reservation price for the option held.

Given the impact of market frictions, it is found that exercise practice on LTOM appears to be largely rational. Thus only 0.57% of the stock option contracts and 1.73% of the index option contracts in the database are exercised in circumstances where a market sale would yield more. Merton's [1973] theorem that call options will not be exercised early except to capture a dividend stream is complied with to a great extent. Only 8.5% of contracts exercised are outside the ex-dividend or expiry accounts and a further 0.76% occur during an ex-dividend account where the dividend stream is too small to justify the early exercise. The major discrepancy is observed in the simultaneous timing of early exercise. The mean proportion of contracts exercised simultaneously in the revised test was 0.675, whilst the hypothesis anticipated a value in excess of 0.95. Exercise on the penultimate day of the account occurs for 91% of the put option sample but only 56.6% of the call option sample. Finally, the hypothesised contraction of the bid-ask spread during the account in which exercise becomes rational is observed for call options but not for puts.

Where irrational behaviour occurs, it is generally to the benefit of the writer of the options, since option holders are exercising in circumstances in which this is not rational. However, the incidence of irrational behaviour is small as are the financial consequences. Hence the writer of option contracts may occasionally be fortunate enough to obtain a small gain from the irrational behaviour of the counterparty, but the probability and expected size of this gain are too small to permit arbitrage trading.

One form of irrational behaviour, namely that of exercising delivery-settled options early in an account, may actually cause financial harm to option writers, since exercise may force them to incur direct transactions costs in the underlying asset, rather than the lower costs which would result from buying back the option position later in the account.

Some of the tests identify marked differences between call and put option subsamples. No obvious reason is found for this. In general, put option exercise practice conforms more closely with theory than does call option exercise practice. This may indicate a clientele effect in the options market, perhaps revealing a greater incidence of inexperienced investors using call options than put options. It is conjectured that the absence of a contraction in the quoted bid-ask spread for put options at the time exercise becomes rational, can be attributed to a clientele effect in the supply of put options, with a significant proportion of the short positions being held by marketmakers.

APPENDIX 3A: IMPLICATIONS OF THE MOVE TO A TEN DAY ROLLING SETTLEMENT SYSTEM

On 18 July 1994, the London Stock Exchange abandoned the account system described in this chapter in favour of a ten day rolling settlement system. "Ten days" in this context means ten working days, or (normally) two weeks. This appendix describes the new system and considers its implications for the hypotheses presented in the chapter.

The system

In the underlying market, stocks bought or sold on, for example, a Wednesday, are settled ten working days afterwards, *i.e.* the second Wednesday after the transaction, (intervening public holidays excepted). Exercise of delivery-settled options is settled within this new system. The option holder has until 16.31 on any working day to decide whether or not to exercise. Assume such a decision is made at 16.25 on a Tuesday. The following day, (Wednesday) an exercise notice is issued to one or more investors holding an aggregate short position equal to the volume of exercise. Settlement of the exercise will occur ten working days after this, *i.e.* Wednesday two weeks later. Exercise is permitted on any working day: the previous restriction that exercise could not be undertaken on the last day of an account was abandoned with the account system.

Consider the case of an investor with an uncovered short position in a call option which is exercised against him on a Tuesday. He receives notice of exercise on the Wednesday: he can purchase the required shares in the market that day. That bargain will be settled ten working days later, *i.e.* the same day that he is obliged to settle the exercise notice. Similarly, consider an investor with a short position in a put option which is exercised against her, again on a Tuesday, so that the exercise notice is received on the Wednesday. She does not want to hold the shares being sold to her through the exercise notice, so she is able to sell these shares on the Wednesday of the exercise notice, again due for settlement at the same time as the exercise notice.

Dividends

Under the account system, stocks were marked ex-dividend at the start of an account. Under rolling settlement, stocks are marked ex-dividend on the first working day of each week, normally a Monday. A company has some flexibility in the choice of its ex-dividend date, but under rolling settlement, for a stock to be marked ex-dividend on a given Monday, an announcement to that effect must have been given by no later than market close on the Tuesday of the preceding week. Hence investors have at least three working days' notice of the ex-dividend event.

Consider an investor with an uncovered short position in a call option exercised against him on the Friday before the stock is marked ex-dividend. The exercise notice will be received on the Monday on which the stock is marked ex-dividend and, in a normal transaction, the shares bought that day would be ex-dividend. However, from the time LTOM was established, it has been a principle that if an option is exercised whilst the underlying stock is trading cum entitlement (*e.g.* dividend or rights), then the shares delivered should also be cum entitlement. This principle has been preserved under rolling settlement: the problem faced by the hypothetical investor who is exercised against on the Friday before an ex-dividend event is solved by his purchasing the shares in a so-called "special cum dividend" transaction on the Monday. The market can accommodate such orders easily enough, although there is generally a small price premium to be paid.

Implications for exercise strategy

Of the five hypotheses presented in the main body of the paper, only one, ("Exercise of delivery-settled options will occur only on the penultimate day of an account"), is affected by the change to rolling settlement. Exercise of put options should now be considered on each working day. Call options, for which early exercise is rational only to capture a dividend, should be exercised only on the Friday before an ex-dividend event. The option holder who exercises on, for example, the Thursday, loses not only the benefit of one day's information flow, but also the benefit of three days' deferral of the payment of the exercise price, since settlement will take place on the Friday two weeks' later, rather than the following Monday. This extra penalty for premature exercise may reduce the incidence of premature exercise of call options seen in Table 3.6.

It is shown in the main text that premature exercise of call options also imposes costs on option writers, since, unless they are seeking to make a permanent or semi-permanent change in their inventory, it is cheaper for them to close their positions through a market transaction rather than through exercise. If rolling settlement does effect a reduction in premature exercise of call options, the risks to call option writers will also thus be reduced.

Other implications for the market

Rolling settlement may have other implications for the options market. It has been suffering from a lack of liquidity in the individual equity options. LIFFE [1994] argue that the abandonment of account trading will lead to an increase in retail use of the equity options market since investors will lose the former facility of being able to hold positions in shares for the two- or three-week duration of an account, without having to part with funds, other than to cover any losses incurred. They argue that the gearing offered by equity option trading will prove an attractive alternative. This conjecture awaits testing.

Appendix 3B. SAMPLE RECORD FOR ABBEY NATIONAL CALL OPTIONS 25 JUNE 1991

Option Series		Open Interest		Daily		Closing	Closing		Today's		Historical		Date of
		Yesterday	Today	Volume	Exercise	USP	Bid	Ask	High	Low	High	Low	Last Trade
Jun	200	158	158				63	65			68	21	24/06/91
Jun	220	181	101	84	16		43	45	45	45	66	16	25/06/91
Jun	240	465	154	436	250		23	25	26	24	47	7	25/06/91
Jun	260	970	940	65			4	6	6	6	31	6	25/06/91
Jun	280	353	353				0	1			19	4.5	12/06/91
Jun	300	25	25				0	1			2	2	03/06/91
Sep	220	74	74				45	49			54	16	13/05/91
Sep	240	762	762				27	31			53	13	04/06/91
Sep	260	425	428	6			13	16	16	16	38	12	25/06/91
Sep	280	249	296	73			6	8	8	6	28	6	25/06/91
Sep	300	7	7				2	3.5			7.5	7.5	12/06/91
Dec	240	106	106				34	39			52	38	21/06/91
Dec	260	20	270	250			20	24	23	23	36	23	25/06/91
Dec	280	130	140	16			11	14	14	12	36	12	25/06/91
Dec	300	104	104				6	8			18	13	12/06/91
Call Totals		4029	3918	930	266	264		Value of OINT		10029800		Value of Volume	2315000

Chapter 4

COMPARATIVE PRICING OF AMERICAN AND EUROPEAN INDEX OPTIONS

4.1 INTRODUCTION

The London International Financial Futures and Options Exchange (LIFFE) appears to be unique in trading both European and American style option contracts on the same underlying stock index (the FT-SE 100). This enables direct comparison of American and European option prices; an aspect of empirical research of equity options markets which appears not to have been undertaken before.

In this chapter, boundary conditions are derived for the comparative pricing of the two styles of option and a database of market bid-ask quotes is used to test compliance with these conditions. *Ex post*, a significant incidence of violation of the conditions is found. The mispricing appears to be unsystematic and a limited test of an *ex ante* trading rule fails to show abnormal profits. An irrational investor preference for American options is found and it is argued that a change of order placement strategy would enable investors to take advantage of the observed mispricing and, eventually, to eliminate it.

This chapter is organised as follows: Section 4.2 contains a review of previous empirical research. In Section 4.3, boundary conditions for the value of the early exercise right are derived. Section 4.4 contains the specification of the tests and the results. Section 4.5 develops this with the specification and testing of an *ex ante* trading rule and suggested alteration to investor order placement strategy. Section 4.6 concludes.

4.2 PREVIOUS RESEARCH

Blomeyer and Johnson [1988] undertake a comparison of the ability of two models to predict the market pricing of American put options. The first is Black-Scholes [1973] (BS). This is a European model and so does not value the early exercise right at all. The second is the Geske-Johnson [1984] model (GJ). They find that both BS and GJ undervalue American put options, although GJ performs substantially better than BS. The performance of the two models is almost identical in the case of short-dated, out of the money puts, for which the probability of early exercise is slight.

Zivney [1991] undertakes a novel boundary condition study. He assumes that European put-call parity holds, and hence any deviation from this in the case of American options must necessarily be a reflection of the value of the early exercise right. Zivney samples closing prices of S&P 100 index options for each trading day of 1985 and finds a mean value of the early exercise right greater than the theoretical values which Blomeyer and Johnson [1988] postulate for individual equity options, even though the value of early exercise should be lower for index options. He concludes with the assumption that the market is efficient and that option pricing models "fail to capture all the nuances of the early exercise decision" (p 137). One of these nuances is the wildcard option, analysed in Chapter 2.

Jorion and Stoughton [1989] compare the pricing of American and European foreign currency options. The ability to exercise early is itself an option and Jorion and Stoughton derive a simple closed-form valuation of this embedded option which compares well with an 'exact' numerical procedure and offers a saving of some 99% of the required computing time.

Cakici, Eytan and Harpaz [1988] compare American and European pricing models for pricing options on the Value Line Index. This is an equally weighted geometric index, posing specific problems for pricing of derivative instruments, since it cannot be duplicated by an actual self-financing portfolio. They find the European model to be effective only in circumstances in which early exercise is improbable.

4.3 BOUNDARY CONDITIONS FOR THE EARLY EXERCISE RIGHT

American call options

Merton [1973] establishes that early exercise of call options on stocks is rational only at the ex-dividend instant and then only if the net present value of future dividends exceeds the value of the benefit of delaying payment of the exercise price until expiry. Rewriting his equation **(12)** in the terms of this thesis, he shows that a sufficient condition for no early exercise is that:

$$X > \frac{\Sigma D}{(1 - e^{-r\tau})} \qquad \textbf{(4.1)}$$

where X is the exercise price, ΣD, the present value of the dividend stream over the remaining life of the option, r, the prevailing riskfree interest rate and τ, the time to expiry.

This study uses **(4.1)** to establish a boundary value, called X^* which is calculated at each ex-dividend event for each expiry. X^* is the maximum exercise price at each ex-dividend event and for each expiry for which early exercise may be rational. It is derived by redefining **(4.1)** as an equation and substituting X^* for X to give:

$$X^{*} = \frac{\Sigma D}{1 - e^{-r\tau}} \qquad \textbf{(4.2)}$$

The prevailing parameters in **(4.2)** are all readily observable and if $X > X^{*}$ for all ex-dividend events, early exercise of the option considered is irrational and hence the American option can be valued as a European option.

American put options

Merton [1973, theorem 4] establishes the *convexity* condition: given three options, identical except for exercise prices X_1, X_2 and X_3 such that $X_1 < X_2 < X_3$, the market prices of these options, M_1, M_2 and M_3, will comply with the following inequality:

$$M_2 \leq \lambda M_1 + (1-\lambda)M_3 \qquad \textbf{(4.3)}$$

where $\lambda = (X_3 - X_2)/(X_3 - X_1)$. Violation can be exploited by purchase of a so-called *butterfly* spread (purchase λ option X_1, sell 1 option X_2, purchase $(1-\lambda)$ option X_3). If the butterfly can be established for a negative, rather than a positive, cost, **(4.3)** is violated.

The convexity condition holds for portfolios of both call and put options, in which the options are either all European or all American. In such form, it has been used to test market efficiency by Galai [1978], Bhattacharya [1983], Halpern and Turnbull [1985] and Chance [1988] *inter alia.* However, **(4.3)** will not necessarily apply to a portfolios in which the options sold short are American and those held long European, because the holder of such a portfolio faces the risk of early exercise of the short position which cannot be matched by the early exercise of the options held long. Thus a compensating value for this must be factored into **(4.3)**.

Consider first the case of a butterfly consisting of European put options. As stated, **(4.3)** will hold for such a portfolio. If the index falls to zero, the value of all options in the butterfly will rise to their upper bound of $Xe^{-r\tau}$. Now assume that X_2, the option sold short, is American rather than European. It will be exercised immediately and its value is thus X_2 rather than $X_2 e^{-r\tau}$. Since **(4.3)** holds for an all-European butterfly, it follows that if a term is incorporated to reflect the difference between the American and European values of option X_2, there will result a boundary condition applying to a mixed European-American-European put option butterfly. This term is $X_2(1-e^{-r\tau})$ giving a boundary condition of:

$$M_2 \leq \lambda M_1 + (1 - \lambda)M_3 + X_2(1 - e^{-r\tau}) \qquad \textbf{(4.4)}$$

4.4 TEST SPECIFICATION AND RESULTS

The database

The database used in this section is drawn from the principal database described in Section 1.4. This is refined to eliminate expiry months which did not contain both American and European options series. The refined database contains 154,402 bid-ask quotations broken down as shown in Table 4.1 below:

	American	European	Total
Calls	57,910	16,110	74,020
Puts	62,186	18,196	80,382
Total	120,096	34,306	154,402

Table 4.1 - Breakdown of sample

Direct comparison of European and American option prices is hindered by the fact that the exercise prices of the two styles of option are offset by 25 index points, in order to avoid confusion in the trading pits. However, the boundary conditions derived in Section 4.3 can be used to provide model-independent tests of the relative pricing.

As shown above, the value of the early exercise right on American call options on a stock index is zero if $X > X^*$ at all ex-dividend events during the life of an option. It is shown in Appendix 4A that early exercise of the call options in the database may be rational only in the case of 9,574 (16.53%) of the total of 57,910 observations of American call options. For the remaining 48,336 observations, the value of the early exercise right is zero. Therefore, these options can be priced as European options.

The comparative market pricing of American and European call options is tested by application of **(4.3)** to the 48,336 observations for which early exercise is demonstrably irrational. Butterfly spreads are constructed using the observations of American call options as X_2 and observations of European options as X_1 and X_3. Since **(4.3)** is applicable to portfolios of European options and since the American options tested have no early exercise value, **(4.3)** is applicable to such portfolios. If the butterfly can be established with a cash inflow, **(4.3)** is violated.

In the case of American put options, **(4.4)** is applied in a similar way with an American put option as X_2 and European put options as X_1 and X_3. If the butterfly can be established with a cash inflow exceeding $X_2(1 - e^{-r\tau})$, **(4.4)** is violated.

The search procedure

To test 48,336 observations of American call options and 62,186 observations of American put options, each of these bid-ask quotes is used as a potential option X_2. Noting the index level at the time of this quote, the database is searched for the next quotes on the same day of European options of the same put or call class with the same expiry and with exercise prices 25 points on either side of option X_2. Each observation thus calls for three options prices: the quoted price of the option sold short and then the next quoted prices for the two options held long. The European options are infrequently quoted so the construction of the triplets of quote observations takes place over an interval. There exists the risk of a distortion of the test, induced by an index change during this interval. This is minimised by requiring the index level at the time of the second and third quotes to be within 2 points (*i.e.* < 0.1%) of the level at the time of the first quote. If the index level at the times of the relevant European quotes does not meet this criterion, the observation is discarded

Even the latitude of $\pm$ 2 index points over the duration of the observation may induce a small bias to the results, which is countered by a second set of results for each test. In these adjusted results, the observed prices of the options held long are increased by $\max[0,|S_{t+1}-S_t|]$, where $S_{t+1}-S_t$ is a change in the index during the observation process which would reduce the price of the options held long (positive for puts, negative for calls).

Results

The results of these tests are contained in Tables 4.2 and 4.3. Violations are measured in index points, which can be converted to sterling at the rate of £10 per index point per contract.

Each table contains two sets of three tests: AAA, in which ask prices are compared with ask prices; BBB, in which bid prices are compared with bid prices; and ABA, in which the bid price of the option sold short in the butterfly spread is compared with the ask prices of the options held long. The ABA test reflects the prices an outside investor would have to pay to establish the butterflies tested. In each table, the first set of results uses the bid-ask quotes as observed. In the second set, prices are adjusted to compensate for any bias caused by market drift during the observation interval, as described above.

Sample	**n**	**Violations**	**%**	**Mean size of violation**	**% of X_2 price**	**Maximum violation**	**Mean duration of observation**
AAA	11,735	3,196	27.23	3.18	7.04	44	109'36"
BBB	11,735	4,838	41.23	3.02	10.52	45	105'12"
ABA	11,735	517	4.41	4.34	6.35	39	134'03"
After adjustment for market drift during observation							
AAA	11,735	2,880	24.54	3.11	6.49	44	107'02"
BBB	11,735	4,408	37.56	2.91	9.42	44	101'39"
ABA	11,735	439	3.74	4.63	6.48	39	130'10"

Table 4.2: Tests of American call options against (4.3)
(American calls sold short, European calls held long)

Sample	**n**	**Violations**	**%**	**Mean size of violation**	**% of X_2 price**	**Maximum violation**	**Mean duration of observation**
AAA	13,037	688	5.28	5.11	3.54	37.63	72'32"
BBB	13,037	801	6.14	5.08	3.88	37.63	77'48"
ABA	13,037	215	1.65	6.01	3.64	32.63	79'08"
After adjustment for market drift during observation							
AAA	13,037	622	4.77	5.12	3.37	37.23	71'03"
BBB	13,037	732	5.61	5.18	3.78	37.23	73'36"
ABA	13,037	196	1.50	6.00	3.49	32.23	79'53"

Table 4.3: Tests of American put options against (4.4)
(American puts sold short, European puts held long)

Tables 4.2 and 4.3 show a notable incidence of overpricing of the early exercise right. The violations are more prevalent for call options than for put options. These findings are superficially in line with those of Zivney [1991] and Blomeyer and Johnson [1988], who find that market valuation of the early exercise right is greater than predicted by theory and also in line with French and Maberly [1992] who identify a 'wildcard' option not incorporated in standard option pricing models. As shown in Chapter 2, the wildcard option in the FT-SE 100 examined here has a life of 21 minutes.

Nevertheless, it may be imprudent to interpret the results of Tables 4.2 and 4.3 in this way. First, all three studies claim to identify flaws in standard option pricing models, but the results in the present study are model-independent. Second, the effect of information arrival during the 21 minute wildcard period was shown in Chapter 2 to be very small.

A further convexity test is undertaken. **(4.3)** will apply to portfolios in which options X_1 and X_3 are American and option X_2 European, since the purchaser of such a butterfly has all the benefits of a European-only butterfly plus the early exercise and wildcard rights on the positions held long. If the violations identified in Tables 4.2 and 4.3 are evidence of systematic overpricing of the early exercise right, few or no violations should be found in the reciprocal cases, where the options held long are American and those sold short European.

Therefore all the observations of European bid-ask quotes for both call and put options are tested against **(4.3)** by constructing American-European-American butterflies using the same search criteria as in the previous tests. The results are shown in Tables 4.4 and 4.5 below. Overpricing of European options is found with about the same order of magnitude as that observed in the tests of American options.

Sample	n	Violations	%	Mean size of violation	% of X_2 price	Maximum violation	Mean duration of observation
AAA	5,418	1,543	28.48	3.83	9.87	46.5	34'52"
BBB	5,418	1,147	21.17	4.10	9.61	46.0	37'41"
ABA	5,418	174	3.21	11.26	12.35	41.5	31'37"
After adjustment for market drift during observation							
AAA	5,418	1,456	26.87	3.82	9.58	46.4	31'59"
BBB	5,418	1,075	19.84	4.11	9.12	46.0	34'09"
ABA	5,418	168	3.10	11.31	12.30	41.4	31'03"

Table 4.4: Tests of European call options against (4.3)
(European calls sold short, American calls held long)

Sample	n	Violations	%	Mean size of violation	% of X_2 price	Maximum violation	Mean duration of observation
AAA	6,420	1,121	17.46	3.09	12.68	39.0	46'26"
BBB	6,420	641	9.98	3.36	14.97	39.0	58'03"
ABA	6,420	108	1.68	7.83	11.97	34.0	59'30"
After adjustment for market drift during observation							
AAA	6,420	1,059	16.50	2.80	11.13	38.5	43'42"
BBB	6,420	602	9.38	3.35	13.61	38.5	53'08"
ABA	6,420	105	1.64	7.79	10.86	38.5	56'53"

Table 4.5: Tests of European put options against (4.3)
(European puts sold short, American puts held long)

Thus it is concluded that the violations observed in Tables 4.2 and 4.3 are not a systematic overpricing of the early exercise right, but rather an indication of an imperfect linkage between the prices of the American and European options. Such imperfection is hard to explain, because the options are traded in the same pit by the same marketmakers, although a number of these choose to trade in the American options only.

4.5 *EX ANTE* SIMULATED TRADING AND INVESTOR ORDER PLACEMENT STRATEGY

Ex ante simulated trading

Given an apparent market imperfection, the next stage is to test whether or not it is tradeable. The impact of the bid-ask spread significantly reduces the ability of an outside trader to exploit the observed mispricing by purchasing the butterfly spreads: this is shown in the markedly decreased incidence of violations in the ABA tests above, compared with either the AAA tests or the BBB tests. Nevertheless, the results of the ABA results indicate that violations occur even after allowing the bid-ask spread. However, these violations are observed *ex post*: a trader cannot be assumed to capture these violations, since the construction of the butterfly spread takes a finite interval and the trader cannot know at the start of that interval that there will subsequently occur prices offering arbitrage opportunities. Since a trader is unable to trade *ex post*, an *ex ante* trading rule is developed and applied to the database in simulated trades to ascertain the likely returns.

Assume a hypothetical trader observing the market and constructing a butterfly spread at the first prices quoted for the constituent options *following* a sufficiently large violation reported above. 'Sufficiently large' is defined as an ABA violation exceeding 1 index point. Assuming 6 contracts of O_2 sold short and 3 contracts each of options O_1 and O_3 held long, a 1 index point violation will offer £60 profit to the trader, sufficient to cover the direct transactions costs imposed by Sharelink, a well-established execution-only broking service. Indirect transactions costs are accounted for by using the bid quote for the options sold short and the ask quotes for the options held long.

The simulation is hindered by market illiquidity. In practice, the hypothetical trader can ask for a quote on any options series at any time. The simulation is restricted to quotes observed in the database, and the search criteria require that there exist quotes for the relevant options series within a time interval during which the index has moved by no more than ± 2 index points. There are more than 1,000 violations to be tested, but the search criteria are met in only 155 cases. The results are presented in table 4.6.

Sample	n	Mean cost	% of X_2 price	Violations	% of sample	Mean violation	% of X_2 price	Maximum violation	Mean duration
American Calls	58	1.38	2.18	12	20.69	10.04	12.78	17.00	53'19"
American Puts	30	6.51	8.73	1	3.33	3.05	3.51	3.05	89'27"
European Calls	45	5.07	7.28	2	4.44	5.00	5.26	5.00	2'35"
European Puts	22	9.11	18.93	0	0.00	0.00	0.00	0.00	0'00"

Table 4.6: Results of simulated arbitrage trades

Table 4.6 indicates that the trading rule would not be profitable. The mean cost of establishing the butterfly spreads is positive for all samples, whereas the objective is to establish these spreads at a negative cost. However, the constraints of the market illiquidity described above mean that there is only a very limited number of observations in the simulation.

Investor order placement strategy

It has been noted above that there is more liquidity in the American options than in the European. Table 4.1 shows that the quotes for American options outnumber those for the European options by a factor of nearly four. The difference in volume traded is even greater: LIFFE data show that the ratio over the period examined was approximately five to one in the case of put options and almost seven to one in the case of calls. Jorion and Stoughton [1989, footnote 1] find a similar lack of interest in European foreign currency options.

Yet in the case of index call options, this investor preference for American rather European options is unjustified. Early exercise is irrational for the great majority of American call options traded. Thus investors seeking to open a call option position should be indifferent between the style of option. They may have a preference for exercise price, but the exercise prices of the two styles are offset by only 25 points (*c* 1%).

The options are traded in an open outcry pit. A broker enters the crowd, calls for a quote on a series (thus generating an observation in the database) and, if the price meets the client's requirements, a trade is struck. It is argued here that investors should brief their brokers to call for *two* quotes: one American and the other a nearby European series. The broker would then trade in whichever style appeared to be more finely priced. It is clear that this is not happening at present, because of the difference in the frequency of quotes observed in the database for the two styles of option.

If such a strategy were adopted, a greater frequency of quotes for the European options should be observed, together with an increase in the volume of European options traded and an eventual elimination of the relative mispricing observed in this paper. A similar strategy might also apply for put options, although in this case the early exercise right on the American series will generally have some value.

4.6 CONCLUSION

Boundary conditions are derived for the value of the early exercise right and these conditions are tested in a market trading both American and European options on the same underlying index. These conditions are applied in convexity tests in which the option sold short is American and the options held long, European. A significant incidence of violation is discovered *ex post*, indicating that American options are frequently overpriced. A comparable level of violation is also found when the convexity test is reversed, *i.e.* the option sold short is European and those held long, American. The mispricing thus appears to be a failure in linkage between the prices of the two styles of option, rather than a systematic overpricing of the early exercise right.

The ability to trade the observed mispricing is hindered partly by the size of the bid-ask spread, and partly because the violations appear to be random, which renders the *ex ante* trading rule unprofitable. Nevertheless, the mispricing appears to be long lasting. The present study analyses the market some two and a half years after the European options were introduced. An earlier, pilot, study[1], observing the market in the six months immediately following introduction of the European options, found similar results.

[1] Details available from the author

Investors show a marked preference for American options, which is irrational, at least in the case of most call options. A superior order placement strategy for investors opening a position is presented. They should not restrict their sights to an American option but call for quotes on two options series, an American one and a nearby European one, and trade in the series which appeared to be more finely priced. It is predicted that such a strategy will lead to an increase in the volume of European options traded and will eradicate the comparative mispricing observed in this paper.

Appendix 4A: FILTER OF AMERICAN CALL OPTIONS FOR WHICH EARLY EXERCISE MAY BE RATIONAL

Merton [1973] establishes a sufficient condition for early exercise of call options to be irrational. This is modified in section 4.3 to derive the maximum exercise price, X^*, at any ex-dividend instant for which early exercise may be rational. The modified equation is

$$X^* = \frac{\Sigma D}{(1 - e^{-r\tau})} \tag{4.2}$$

where ΣD is the present value of the dividend stream until the expiry of the option, r, the riskfree interest rate and τ, the time to expiry of the option.

In this appendix, X^* is calculated for each ex-dividend event and each expiry relevant to the database examined in the chapter, to determine which option series may face rational early exercise. For all expiries, the minimum exercise price traded is 2050 and the maximum is 3000. Therefore, early exercise will be irrational for any expiry for which $X^* < 2050$ at all ex-dividend events.

Table 4.7 below shows first, the value of the index fall at each ex-dividend event and the present value of the dividend stream remaining for the life of the option and next the threshold value of X^*, above which early exercise will be irrational. Blank entries indicate that options of a given expiry were not trading at that ex-dividend date. It is seen that exercise is rational in the case of only three expiries, November (for exercise prices below 2277), December (all exercise prices) and February (all exercise prices). These account for 9,574 observations, which are removed from the database, to leave 48,336 observations of American call options to be tested.

It will be noticed that in all cases, only the final dividend payment is capable of triggering rational early exercise.

		Expiry month	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb
		Expiry date	**17.07**	**21.08**	**18.09**	**16.10**	**20.11**	**18.12**	**15.01**	**19.02**
Date	**Dividend**	***r***	**Present value of dividend stream**							
10.07	2.21	0.1000	2.21	14.54	17.93	27.94		47.26		
24.07	5.28	0.1019		12.38	15.78	25.79	32.61	39.71		
07.08	7.13	0.1013		7.13	10.54	20.59	27.44	34.57		
21.08	1.34	0.1025			3.42	13.51	20.39	27.53		
04.09	2.09	0.1019			2.09	12.22	19.12	26.30		
18.09	8.34	0.1050				10.17	17.08	24.28		
02.10	1.84	0.0894				1.84	8.77	16.02	18.40	
16.10	2.79	0.0788					6.97	14.26	16.65	
30.10	1.20	0.0775					4.19	11.50	13.90	21.19
13.11	3.00	0.0688					3.00	10.34	12.74	20.07
27.11	2.12	0.0719						7.36	9.77	17.11
11.12	5.25	0.0706						5.25	7.67	15.04
31.12	2.43	0.6875							2.43	9.83
15.01	0.96	0.6875								6.45
29.01	0.08	0.0625								6.47
12.02	6.41	0.0600								6.41
Date			**X^* (values which embrace open series shown in bold)**							
10.07			1153	1271	944	1055		1095		
24.07				1591	1017	1113	998	988		
07.08				1840	910	1071	956	954		
21.08					437	866	808	838		
04.09					536	1049	899	911		
18.09						1268	951	940		
02.10						538	735	857	725	
16.10							926	1056	856	
30.10							942	1111	857	902
13.11							**2277**	1573	1080	1098
27.11								1782	1017	1043
11.12								**3879**	1136	1118
31.12									861	1048
15.01										982
29.01										1804
12.02										**5574**

Table 4.7: Filtering of American call options for which early exercise may be rational

The filter assumes certain foreknowledge. For example, the November options started trading in July and it is assumed that the market would be able to predict both the size of the ex-dividend fall at each ex-dividend event during the options' life and the interest rate prevailing at each such event. The first assumption is reasonable, since the stocks comprising the index are all widely researched and any individual dividend surprise will have little effect on the index fall. Interest rate predictions would need to use implied forward-forward rates which *ex post* show themselves to be either reasonable predictors of the prevailing rates or, following the turbulence in the sterling markets on September 16, 1992, predictors of too high a rate. The usage in the table below of the lower, prevailing, rates is therefore a more stringent test, since it filters out more series than would be filtered by the implied forward-forward rates.

Chapter 5

COMPETING WITH MARKETMAKERS THROUGH LIMIT ORDERS

5.1 INTRODUCTION

A limit order is an option on a financial asset. With limit bid orders, investors give the market at large the right but not the obligation to sell a fixed quantity of a specified asset at a predetermined price within a specified timeframe - an American put option. A limit ask order has the characteristics of an American call option. The granting of any option involves an assumption of risk, since the option is exercised at the taker's discretion and the taker's interests will generally be opposite to those of the grantor. However, investors who grant options by way of placing limit orders receive no monetary reward for so doing, and thus appear to be unrewarded for their risk. Their gain comes in the form of an opportunity to trade at more advantageous prices than are quoted in the market. In this chapter, the risks and rewards of placing limit orders on stock and stock index options traded on the London International Financial Futures and Options Exchange (LIFFE) are analysed.

Limit orders have received considerable theoretical attention, but little empirical analysis. This chapter contributes in several ways: first, two classes of limit order are identified, reflecting the two different roles which they play for investors. Next, it is shown that limit-order investors face very different risks from the marketmakers with whom they are assumed to compete. Finally, using only weak assumptions, a simple trading rule is developed which offers a significant (1%) increase in the effectiveness of limit order strategy over observed practice, by circumventing some of the risks which limit order investors would otherwise face. This trading rule is tested against advice given by Silber [1988] to public investors on an options market and evidence is found to justify rejection of this advice.

This chapter is organised as follows: n Section 5.2, the information risks inherent in limit order placement are reviewed. Section 5.3 presents the database and methodology. The results of the analysis of the database follow in Section 5.4 and an empirical limit order strategy is derived and tested in Section 5.5. Section 5.6 concludes.

5.2 INFORMATION RISKS IN LIMIT ORDERS

The CMSW [1981] model

Cohen, Maier, Schwartz and Whitcomb (CMSW) [1981] develop a rational order placement strategy, given the possibility of both limit and market orders. The investor considering a purchase[1] order at time t has three choices:

a. submit a market order at the current market ask price, P_t^{MA},

b. submit a limit bid order at a lower price, $P_t^{LB} < P_t^{MA}$, or

c. do nothing.

Assuming a default choice of *c.*, CMSW describe a utility gain function, $\Delta U = f(P_{target})$, where P_{target} is the investor's target price for the asset, which leads to three local maxima:

i. at a limit bid price P_t^{LB} below the current market bid price, P_t^{MB}, where the probability of execution is low, but the price particularly attractive;

ii. at a limit bid price P_t^{LB} at or above the current market bid price, P_t^{MB} but below the current market ask price, P_t^{MA}, where the probability of execution < 1, but higher than in case *i.* and the price more attractive than the current market ask; and

iii. at the current market ask price, P_t^{MA}, where the probability of execution is 1.

Thus if the prevailing market quote is 100 bid, 110 offered, case *i.* would be a limit bid order at less than 100, case *ii.* a limit bid order at 100 or higher, but less than 110 and case *iii.* a market order at 110.

[1] The case of sell orders is symmetric.

The investor's rational choice is prescribed by max (ΔU). If max (ΔU) < 0, no action is taken. Otherwise, a limit order is placed at either price $P_t^{LB} < P_t^{MB}$ or price $P_t^{MB} \leq P_t^{LB} < P_t^{MA}$ or a market order is placed at price P_t^{MA}, depending on which of the three local maxima is greatest.

Two types of limit order

Whereas CMSW regard the investor as having three choices: do nothing, limit order or market order, this chapter stresses the distinction in kind between case *i.* (a limit order placed outside the quoted spread) and case *ii.* (a limit order placed at or within the quoted spread[2]). In case *i.*, the probability of execution is zero unless some new information on the underlying asset is absorbed by the market to bring the market quotes to the same level as the limit price. In case *ii.*, limit orders have a positive probability of execution even without a movement in the price of the asset.

The distinction between these two cases is important because it identifies the two different roles which limit orders play. Case *ii.* exemplifies Demsetz's [1968, p43] description of the competition to marketmakers provided by "outsiders who submit limit orders rather than market orders." Another example of this view is in Logue [1975, p119] who states that limit orders "compete with the market-maker". Conroy and Winkler [1986, p22] also refer to "competition in the form of public limit orders." These descriptions of the role of limit orders fit case *ii.* well but are hardly applicable to case *i.* As Berkman [1991, p10] points out, a limit order placed outside the market quote gives the marketmaker a free insurance: far from being competition, it is actually an asset to the marketmaker.

[2]Note that under LIFFE rules, limit orders generally take precedence over marketmaker quotes at the same price.

Case *i.* accords rather better with Garbade's [1982, p448] description of a limit order as "an economical alternative for a floor broker who would otherwise have to maintain a physical presence at a post to keep a limited price bid or offer active." In effect, limit bid orders at price $P_t^{LB} < P_t^{MB}$ (or limit ask orders at price $P_t^{LA} > P_t^{MA}$) enable investors to capture attractive prices without the need to monitor the market continuously. Such orders can be classified as **monitoring** orders. Case *ii.* orders provide competition to the marketmakers, and can be classified as **competing** orders. Developing the analogy of limit orders as options in themselves, a monitoring limit order can be described as out of the money whereas a competing order is at the money.

Silber [1988, p24] advises public investors not to try to compete with marketmakers in options markets. No justification is given: merely an assertion that "the best advice is to hit bids and lift offers; paying the liquidity costs is usually the least expensive component of a speculative transaction."

The effect of adverse and beneficial information

Investors who place limit orders on LIFFE face two types of information risk: adverse and beneficial. These are not well documented in the literature. Consider the following examples, both taken from the database. In the first, at 09.21, an investor wants to buy one Kingfisher October 500 Call contract, presumably expecting a rise in the option price. The underlying stock price is 469p and the market quote for the option is 14p-18p. A limit bid order is placed at 16p, with the investor thus hoping to capture 50% of the market spread. New information arrives in the market at 13.43, depressing the stock price to 462p. Immediately the limit order is executed and the new market quote for the series is 11p-15p. Thus the limit order has caused the investor to buy at a price 1p above the updated market ask. A semi-strong form inefficiency has been offered to the market and seized immediately.

It might be argued that the investor is paying the price for an incorrect market movement forecast and is, in any case, 2p better off than through a trade at the market ask price prevailing at 09.21. However, in return for this 2p, the investor has not only borne the risk of ***adverse*** information, as shown in the example above, but also the risk of the arrival of ***beneficial*** information before the transaction is executed, as shown in the second example, also taken from the database.

At 10.20, an investor wants to sell five Glaxo September 750 Call contracts, presumably expecting a fall in the option price. The underlying stock is 795p and the prevailing option quote is 82p-89p. A limit ask order is placed at 89p, with the investor thus hoping to capture all of the prevailing spread. The stock price (and hence the option price as well) falls rapidly through the day and the closing option quote is 65p-70p. The investor's forecast of the option price movement is correct and the limit remains unexecuted precisely because the option price has moved in line with the investor's expectations, moving the limit price outside the market spread.

Thus these competing limit orders carry an inbuilt bias: new information, favourable to the investor's desired position in the options, will reduce the probability of execution, whereas adverse information will increase it. A limit order was described above as a short position in an option and the examples above are consistent with this. In the Kingfisher example, the underlying price falls below the exercise price (*i.e.* the investor's limit bid price) and the put option is exercised. In the Glaxo example, the underlying price falls below the exercise price and the call option is not exercised.

The risk of adverse information triggering exercise has received passing reference in previous work. Miller [1990] mentions this while discussing the social value of stock-index arbitrage, recommending the introduction of contingent limit orders to help reduce the risk and Stein [1990] implies its existence in discussing order placement strategy for less liquid options.

Copeland and Galai [1983] also characterise marketmaking activity in the supply of bid and ask quotes as taking short positions in put and call options. Nevertheless, marketmakers in LIFFE's options pit take such positions only momentarily because their quotations are good only for the instant at which they are issued and their physical presence in the market enables them to adjust quotations rapidly in response to new information. Limit orders on LIFFE are good for the day and, whilst they may be withdrawn at any time, the communications process inevitably involves a delay and effectively prevents withdrawal in response to adverse information. Thus the put and call options embedded in marketmakers' bid and ask quotes have an instantaneous maturity, whereas delays in communication mean that the equivalent options embedded in limit orders have a much longer maturity. Hence marketmakers do not face the twin information risks borne by limit order investors.

5.3 DATABASE AND METHODOLOGY

The Public Limit Board on LIFFE

The Public Limit Board is available to retail clients only: LIFFE do not want to offer institutional clients facilities for 'fair weather marketmaking'. Definition of a retail client is vague; order size is the most important criterion. If challenged on this point, the broker placing the order must prove that the investor is a ***bona fide*** retail client. Contingent limit orders are not permitted. There is no exchange fee for placing a limit order, although some brokers, but not all, do charge a fee for this.

Conroy and Winkler [1981] discuss access to limit order information. Within the trading pit on LIFFE, all participants can readily see the full range of limit orders displayed on computer screens, although for options series where there exist several limit orders, there is room for only the most competitive of these. Outside the market, prices are distributed by a variety of quote vendors, during the period of the database used in this study[3], these generally did not display limit orders unless they formed one or both sides of the market spread. In such cases, the fact that these were limit orders was revealed by colour coding, although the size of the order was not revealed.

Databases

Two databases are used in this chapter:

i. a record of all orders placed on the public limit board. This identifies options series, date and time of order placement, limit price and size of order and whether it is an ask or a bid order; and

ii. the time- and date-stamped record of all bid and ask quotes and all transactions prices for all options series, together with a simultaneous record of the price of the underlying asset, as described in Section 1.4.

An extract from database *i.* is contained in Appendix 5A. With these databases a comprehensive picture of public limit board activity during the periods studied can be obtained. Database *i.* shows the placing of limit orders and database *ii.* puts this into context. Bid-ask quotes on database *ii.* are generated whenever a participant calls for a quote. This generally happens before a limit order is placed, which thus normally gives synchronous information on the market quote prevailing at the time of order placement which in turn enables orders to be classified as competing or monitoring.

[3]Information on Public Limit Orders is now more widely available

Database *ii.* also enables recognition of limit order execution by identifying transactions occurring at the limit price after the order is placed and in addition, it gives the bid-ask quotes prevailing at market close. The sample contains 7,563 observations of limit orders; a breakdown is given in table 5.1 below:

	Stock option orders		Index option orders		Total	
Observations	4,584		3,069		7,563	
Executed	1,396	*30.45%*	1,689	*55.03%*	3,085	*40.31%*
Unexecuted	3,188	*69.54%*	1,380	*44.97%*	4,568	*59.69%*
Calls	3,126		1,585		4,711	
Executed	1,056	*33.68%*	866	*54.64%*	1,922	*40.80%*
Unexecuted	2,070	*66.32%*	719	*45.36%*	2,789	*59.20%*
Puts	1,458		1,484		2,942	
Executed	340	*23.32%*	823	*55.46%*	1,163	*39.53%*
Unexecuted	1,118	*76.68%*	661	*44.54%*	1,779	*60.47%*
Bid	1,826		1,314		3,140	
Executed	517	*28.31%*	697	*53.04%*	1,214	*38.66%*
Unexecuted	1,309	*71.69%*	617	*46.96%*	1,926	*61.34%*
Ask	2,658		1,755		4,423	
Executed	897	*33.07%*	992	*56.52%*	1,871	*43.30%*
Unexecuted	1,779	*66.93%*	763	*43.48%*	2,552	*57.70%*
Competing	3,683		1,902		5,585	
Executed	1,216	*33.02%*	1,171	*61.57%*	2,387	*42.74%*
Unexecuted	2,467	*66.98%*	731	*38.42%*	3,198	*57.26%*
Monitoring	321		611		932	
Executed	34	*10.59%*	243	*39.77%*	277	*29.72%*
Unexecuted	287	*89.41%*	368	*60.23%*	655	*70.28%*

Table 5.1: Breakdown of limit order database

Table 5.1 shows a distinctly higher incidence of execution of index limit orders than of stock limit orders. This is not a consequence of the different timeframes analysed, because the difference remains significant (1%) when the overlapping period, 1-10 July 1992 is analysed.

Quantification of success

Some method of quantifying the success of limit orders is needed. The CMSW [1981] model calls for analysis of investors' utility functions. Such strong assumptions are avoided in the present study. Instead, a point in time is chosen at which the investor is assumed to review the outcome of the limit order, *i.e.* executed or not executed, and, by comparison with the market price prevailing at that time, assess its success. Since limit orders are good for the day, the natural moment to undertake such an assessment is at the end of the day on which the order is placed.

First consider executed orders. The investor has either bought at price P_t^{LB} or sold at price P_t^{LA}. At market close, the same transactions would need to be executed at prices P_{close}^{MA} or P_{close}^{MB} respectively. At the time of review, the investor would regard the outcome as successful if bid orders had been executed at a price lower than the prevailing market ask or if ask orders had been executed at prices higher than the prevailing market bid. Therefore the success of an executed limit order is quantified by the statistics $R_{close} = P_{close}^{MA} - P_t^{LB}$ for bid orders and $R_{close} = P_t^{LA} - P_{close}^{MB}$ for ask orders. The comparison is made with closing ask prices for limit bid orders (and closing bid prices for limit ask orders) because it is reasonable to assume that the investment horizon extends beyond the day the order is placed: the alternative, in which limit bid orders are compared with closing bid prices and limit ask orders with closing ask prices assumes that the investor will only regard the outcome as positive if the options position can be profitably reversed at the market prices prevailing at the end of the trading day. This seems an excessively tight restriction on the investment horizon.

Now consider unexecuted orders. In the case of limit bid orders, the investor had the option to trade at price P_t^{MA} but chose to submit a limit order instead. At the time of review, the investor has the option to trade at price P_{close}^{MA}. If $P_{close}^{MA} < P_t^{MA}$, the best market price available to the investor has improved as a result of the decision to place a limit order rather than a market order at time t. Such an outcome can be regarded as a success; whereas if $P_{close}^{MA} > P_t^{MA}$, the outcome can be regarded as a failure. The success of an unexecuted bid order is therefore quantified by the statistic $R_{close} = P_t^{MA} - P_{close}^{MA}$. For unexecuted ask orders, the statistic $R_{close} = P_{close}^{MB} - P_t^{MB}$ is used. The sign in these definitions is chosen so that successful outcomes have a positive value of R_{close} and unsuccessful outcomes have a negative value. Since Table 5.1 showed significant differences between index and stock option orders and between monitoring and competing orders, the R_{close} statistic is analysed by these subsamples[4].

5.4 RESULTS

After elimination of observations for which no closing bid-ask quote was available, the mean values of the R_{close} statistics are presented in Table 5.2 below:

		Executed		Not executed		Total	
		n	Mean	n	Mean	n	Mean
Competing	**Stock**	*930*	0.5720	*2,174*	-0.5113	*3,104*	-0.1867
	Index	*1,163*	0.4720	*730*	-2.2650	*1,893*	-0.5835
	Total	*2,093*	0.5170	*2,904*	-0.9521	*4,997*	-0.3368
Monitoring	**Stock**	*25*	0.5400	*253*	-0.0630	*278*	-0.0088
	Index	*242*	-0.0270	*363*	-1.9260	*605*	-1.1664
	Total	*267*	0.0260	*616*	-1.1600	*883*	-0.0821
Total	**Stock**	*955*	0.5712	*2,427*	-0.4646	*3,382*	-0.1721
	Index	*1,405*	0.3860	*1,093*	-2.1520	*2,498*	-0.7240
	Total	*2,360*	0.4610	*3,520*	-0.9886	*5,880*	-0.4057

Table 5.2: Mean values of R_{close}

[4]Table 5.1 also showed significant differences between Put and Call options and Bid and Ask orders in the Stock options sample. In the analysis which follows, these differences are insignificant, so they are omitted from the presentation: details are available from the author.

The prevalence of negative numbers in the final column of Table 5.2, all significantly (1%) negative except Monitoring-Stock, indicates that investors using the public limit board can expect failure, as measured by the criteria presented above. The generally positive values in the Executed column show success in those cases where orders are executed, but this is outweighed by the incidence and size of failure among unexecuted orders. This accords with the information risks described above: adverse information will help to trigger execution, lowering the gains, whereas beneficial information will reduce the incidence of execution and increase the losses.

Further analysis of Table 5.2 is undertaken. The objective is to find a relationship between the size of the spread which the investor hopes to capture and the outcome, as measured by the R_{close} statistics. The target spread capture is measured in two ways: absolute (T_{abs}) and proportional (T_{pro}). They are defined as shown in Table 5.3 below:

	T_{abs}	T_{pro}
Limit bid orders	$P_t^{MA} - P_t^{LB}$	$\frac{P_t^{MA} - P_t^{LB}}{P_t^{MA} - P_t^{MB}}$
Limit ask orders	$P_t^{LA} - P_t^{MA}$	$\frac{P_t^{LA} - P_t^{MA}}{P_t^{MA} - P_t^{MB}}$

Table 5.3: Definition of absolute (T_{abs}) and proportional (T_{pro}) target spread capture measures

Each observation is allocated to one of ten portfolios by the size of the observed T_{abs} values and one of ten portfolios by the size of the observed T_{pro} values and the mean R_{close} value for each portfolio analysed. If certain target spread capture values are demonstrably successful or unsuccessful, this will be apparent by significantly positive or negative R_{close} values for the appropriate portfolio. The results of this analysis are presented in Table 5.4 below:

T_{abs}	STOCK ORDERS n	Mean R_{close}	t	Incidence of execution	INDEX ORDERS n	Mean R_{close}	t	Incidence of execution
½-1p	671	-0.0214	-0.31	35.50%	142	-0.0980	-0.15	69.93%
1½-2p	601	-0.3551	-3.93	32.28%	306	-0.3640	-0.80	74.11%
2½-3p	196	-0.4217	-2.07	31.31%	264	-0.6210	-1.00	63.02%
3½-4p	77	-0.0260	-0.01	23.38%	140	0.2040	0.27	57.14%
4½-5p	40	0.1500	0.27	20.00%	93	-1.8500	-1.65	45.16%
5½-6p	7	0.1429	0.16	14.30%	8	-3.1200	-1.51	25.00%
6½-7p	8	2.1250	1.94	37.50%	7	5.5700	2.52	71.40%
7½-8p	3	3.3330	2.00	0.00%	9	-1.3300	-0.48	33.33%
8½-9p	2	0.0000	*	0.00%	6	9.0000	*	*
9½-10p	2	9.0000	*	100.00%	11	0.4500	0.15	36.40%
T_{pro}	n	Mean R_{close}	t	Incidence of execution	n	Mean R_{close}	t	Incidence of execution
0.0001-0.1	0	*	*	*	0	*	*	*
0.1001-0.2	14	-1.9300	-1.52	50.00%	3	-2.3300	-1.26	100.00%
0.2001-0.3	39	-0.6410	-1.58	33.33%	2	3.0000	0.60	50.00%
0.3001-0.4	121	-0.1070	-0.52	47.93%	18	-0.8900	-0.35	72.20%
0.4001-0.5	237	-0.1360	-1.19	33.89%	63	-0.4600	-0.49	71.43%
0.5001-0.6	27	-0.7410	-1.15	40.74%	47	-1.7800	-0.87	56.25%
0.6001-0.7	187	-0.0920	-0.77	30.98%	53	1.2400	0.95	73.58%
0.7001-0.8	108	-0.1960	-0.99	22.43%	85	0.1510	0.19	61.63%
0.8001-0.9	0	*	*	*	0	*	*	*
0.9001-1.0	874	-0.1445	-1.76	32.00%	715	-0.4770	-1.45	62.69%

Table 5.4: Mean R_{close} values by target spread capture

Table 5.4 fails to show any particularly successful or unsuccessful target spread capture values. The analysis of the T_{pro} portfolios is hampered by the fact that a large percentage of both the stock (54.4%) and the index (72.5%) limit order samples have a T_{pro} value of 1.

It would be possible to conclude from Tables 5.2 and 5.4 that the twin information risks borne by limit order investors outweigh the returns. Nevertheless, the value of a public limit order facility should not be dismissed without an attempt to develop a more effective strategy than that used by the average investor considered so far.

5.5 AN EMPIRICAL LIMIT ORDER STRATEGY

In this section, a more sophisticated strategy is developed and tested. The specific objective is to derive a realistic strategy capable of generating significantly higher R_{close} values than found already. The criterion of "realistic" is defined as a strategy which it is reasonable to expect a retail investor to undertake: in particular, any strategy which calls for continuous monitoring of the marketplace is ruled out. Only two assumptions are made in this section, and they are both weak. First, it is assumed that the implementation of the strategy would not alter the the bid and ask quotes observed in the database. This assumption is addressed in the concluding section. Second, it is assumed that the market closing prices (and hence the R_{close} values which are derived from them) are a reasonable criterion for determining the success or failure of the strategy. Importantly, no assumptions are made about option pricing models, order arrival rates or investor utility functions.

It is essential to avoid any *ex post* sample selection bias, so the following procedure is adopted. The stock orders database covers 76 trading days, with a midpoint of 18 May 1992. The index orders database covers 96 trading days, with a midpoint of 7 September 1992. The databases are divided in two at these midpoints, with the first half of each database used to derive a strategy and the second half used to test it. Thus the simulation is of a stock (index) options investor who, on 18 May (7 September), uses observations of the previous 38 (48) trading days to derive a strategy which is then tested *ex ante* over the following 38 (48) days. The strategy derived will be deemed successful if it generates a significant increase in the mean R_{close} values for the second half over those currently observed.

Monitoring orders form only a small part (12%) of the database and thus there are small samples of these when the database is divided in two, so the strategy derivation is restricted to competing orders only.

Sample period statistics

Table 5.5 below gives the mean observed R_{close} values for competing orders in the first and second halves of the sample. The objective is to generate a significant increase in the second half R_{close} values.

		Executed		Not executed		Total	
		n	**Mean**	**n**	**Mebn**	**n**	**Mean**
Stock	**First half**	*526*	0.5247	*1,081*	-0.5204	*1,607*	-0.1783
	Second half	*403*	0.6340	*1,069*	-0.5065	*1,472*	-0.1943
Index	**First half**	*631*	0.5330	*355*	-2.0870	*986*	-0.4100
	Second half	*524*	0.3850	*351*	-2.6250	*875*	-0.8220

Table 5.5: Mean R_{close} values for first and second half samples

Strategy derivation

i. Market orders

It is shown in table 5.5 above that the lack of success ($R_{close} < 0$) arises mainly from the Not executed column. In other words, investors miss out on favourable market movements by submitting limit orders rather than trading at the market quote. The first approach is therefore to consider how investors would have fared if they had submitted market orders rather than limit orders. Thus limit bid orders would have been executed at price P_t^{MA} and limit ask orders at price P_t^{MB}. In such a situation, the success measure, R_{close}, is defined as P_{close}^{MA} - P_t^{MA} for bid orders and P_t^{MB} - P_{close}^{MB} for ask orders. This strategy accords with Silber's [1988] advice and proves to be ineffective. The mean R_{close} value rises from -0.1783 to -0.0450 for stock orders, but falls from -0.4100 to -0.6290 for index orders. In both cases, the changes are not significant at the 5% level.

ii. Time limit on limit orders

The next approach towards deriving a performance-improving strategy is a modification of the first. The previous approach, calling for the use of market orders at all times, was ineffective because it deprived investors of any benefit from limit orders. A hybrid is now tried, with the objective of capturing some of the benefits of limit orders, but also capturing some of the gains from the arrival of beneficial information.

The approach is based on the idea that there may exist an optimal interval, τ', after which the limit order should be withdrawn if it has not been executed and the investor should trade at the market price prevailing at time $t+\tau'$. The idea is similar to the finding by Silber [1984] that the trades of a scalper in a futures market were likely to be unprofitable if they were not unwound within three minutes. The optimal value of the interval, τ', is derived empirically, by analysis of the first half of the sample to determine the cumulative rate of execution by 15 minute intervals after order placement. The results are shown in Figure 5.1 below.

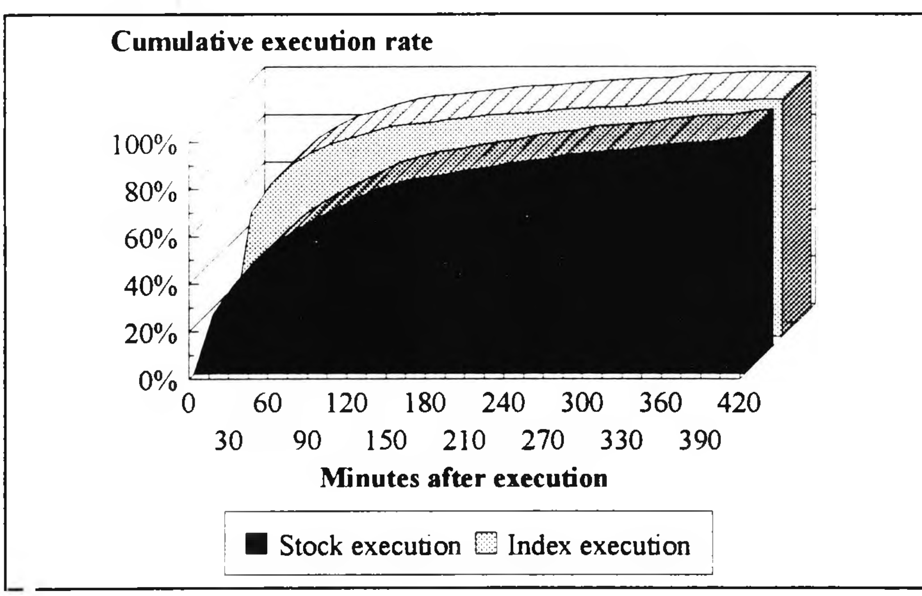

Figure 5.1: Cumulative rate of execution of limit orders

It is clear from Figure 5.1 that the cumulative execution rate is steep in the interval immediately following order placement and that it flattens considerably in later hours. Thus, of those limit orders for stock options which are executed, almost half are executed within one hour of order placement and for index orders, the proportion exceeds three quarters.

From this, the following trading rule is used: place limit orders as observed, but if these are not executed within a prescribed interval, τ', after placement, withdraw the limit order and trade at the relevant bid or ask price prevailing at the end of the interval. In this way, all orders will be executed; the investor has the chance to exploit the limit board for a demonstrably productive interval, but also to put a limit on the length of exposure to the risk of beneficial information. Hence this strategy reduces reduces risk and must, therefore, dominate observed practice if it offers a significant increase in R_{close} values. The interval, τ', is selected empirically, by considering *ex post* the effectiveness of different intervals on the derivation database. Values of $\tau' = 0$, 30, 60, 90 and 120 minutes are tested ($\tau' = 0$ reflects alternative *i.* above, in which all orders are executed at market prices). The results are shown in Table 5.6 below

	Executed at limit price		Executed at market price		Not executed		Total				Difference	
STOCK ORDERS												
	n	Mean R_{close}	*n*	Mean R_{close}	*n*	Mean R_{close}	n	Mean R_{close}	σ	*t*	Mean ΔR_{close}	*t*
Observed	526	0.525	0	0.000	1,081	-0.520	1,607	-0.178	2.29	*-3.12*		
τ' = 0	0	0.000	1,607	-0.045	0	0.000	1,607	-0.045	2.45	*-0.82*	0.133	*1.50*
τ' = 30	198	0.583	1,409	-0.068	0	0.000	1,607	0.012	2.26	*0.21*	0.190	*2.58*
τ' = 60	287	0.512	1,320	-0.054	0	0.000	1,607	0.047	2.16	*0.88*	0.226	*3.27*
τ' = 90	342	0.618	1,265	-0.061	0	0.000	1,607	0.084	2.14	*1.57*	0.262	*3.91*
τ' = 120	384	0.482	1,223	-0.037	0	0.000	1,607	0.087	2.15	*1.63*	0.265	*3.93*
INDEX ORDERS												
	Executed at limit price		**Executed at market price**		**Not executed**		**Total**				**Difference**	
	n	Mean R_{close}	n	Mean R_{close}	n	Mean R_{close}	n	Mean R_{close}	σ	*t*	Mean ΔR_{close}	*t*
Observed	631	0.533	0	0.000	355	-2.087	986	-0.410	9.02	*-1.43*		
τ' = 0	0	0.000	986	-0.629	0	0.000	986	-0.629	9.19	*-2.15*	-0.219	*-0.58*
τ' = 30	409	0.716	577	-1.038	0	0.000	986	-0.310	9.73	*-1.00*	-0.100	*-0.25*
τ' = 60	490	0.618	496	-0.491	0	0.000	986	0.060	9.37	*0.20*	0.471	*1.27*
τ' = 90	529	0.564	457	-0.665	0	0.000	986	-0.006	9.04	*0.0*	0.405	*1.12*
τ' = 120	560	0.392	426	-0.352	0	0.000	986	0.070	8.77	*0.25*	0.481	*1.37*

Table 5.6: Mean R_{close} values for different values of τ' on first half of sample

The first row in each half of Table 5.6 reflects the average position as observed in the marketplace and as recorded in Table 5.5 above. Of the 1,607 stock order observations, 526 are executed and 1,081 are unexecuted with an overall mean R_{close} value of -0.178. The objective is to improve on this figure. The rows below show the outcome if the order is allowed to stand for a maximum of τ' minutes and then executed at the prevailing market price if it has not already been executed within the τ' minute interval. Thus, in these rows, all orders are executed, either at the limit price or at the market price prevailing at time $t+\tau'$. The greater the interval, τ', the greater the probability of execution, but also, the longer the exposure to the risk of beneficial information arriving, thus moving the market price away from the investor for unexecuted orders.

The key statistics are the Mean R_{close} and Mean ΔR_{close} figures in the Total and Difference columns on the right-hand side of the table. The Difference statistic reflects the mean improvement that the strategy with the τ' minute interval offers over the Observed Mean R_{close} statistic. t tests are also conducted on the null hypotheses that these statistics equal zero. The maximum differences for both stock and index orders are observed when $\tau' = 120$ minutes, although for index options, the result at $\tau' = 60$ minutes is almost identical to the result at $\tau' = 120'$. The performance improvement is significant (1%) for stock orders but not for index orders. The risks of the different strategies, as measured by the standard deviations of the R_{close} statistics, show little variation across the range of values of τ' but it is seen that the standard deviations are much higher for index orders than for stock orders.

***Ex ante* test**

The results in Table 5.6 are derived *ex post* from the first half of the sample. The strategy will have merit only if it can be shown to be effective *ex ante*. The trading rule ($\tau' = 120$ minutes for both stock and index orders) is then tested *ex ante* on the database for the second half of the sample. The results are presented in Table 5.7 below. They are very similar to the equivalent results in Table 5.6, in that the stock orders rule shows a significant (1%) increase in performance (0.361 pence), but the improvement for index orders, whilst positive (0.647 points), is not significant even at the 5% level. The strategy is thus supported *ex ante* for stock orders, but not for index orders.

Silber's [1988] advice

Silber's [1988] advice that public investors in options markets should not attempt to compete with marketmakers was noted above. The strategy tested above is a direct contradiction of this advice. It can be tested against Silber's advice by a comparison of the prices at which orders are executed under the two systems

Investors who follow Silber will trade at P_t^{MA} for bid orders and P_t^{MB} for ask orders. This is equivalent to setting $\tau' = 0$. Investors following the strategy proposed here will trade at P_t^{LB} for bid orders which are executed within the 120 minute interval and $P_{t+\tau}^{MA}$ for bid orders which are not executed within this interval. The corresponding prices for ask orders are P_t^{LA} and $P_{t+\tau}^{MB}$. In this case, $\tau' = 120$. The test is simple: which of the two alternatives ($\tau' = 0$, or $\tau' = 120$) produces the lower buying or higher selling prices?

	Executed at limit price		Executed at market price		Not executed		Total				Difference	
STOCK ORDERS												
	n	Mean R_{close}	n	Mean R_{close}	n	Mean R_{close}	n	Mean R_{close}	σ	t	Mean ΔR_{close}	t
Observed	403	0.634	0	0.000	1,069	-0.507	1,472	-0.194	2.25	*-3.31*		
$\tau' = 120$	267	0.818	1,205	0.022	0	0.000	1,472	0.167	1.99	*3.22*	0.361	*5.19*
INDEX ORDERS												
	Executed at limit price		**Executed at market price**		**Not executed**		**Total**				**Difference**	
	n	Mean R_{close}	n	Mean R_{close}	n	Mean R_{close}	n	Mean R_{close}	σ	t	Mean ΔR_{close}	t
Observed	524	0.385	0	0.000	351	-2.625	875	-0.820	11.6	*-2.20*		
$\tau' = 120$	453	0.142	422	-0.512	0	0.000	875	-0.173	11.0	*-0.41*	0.647	*1.69*

Table 5.7: Results of *ex ante* tests of trading rules using second half of sample

Since the objective is to secure lower buying prices and higher selling prices, the test statistics are $\Delta P^{trade} = P_t^{LB} - P_t^{MA}$ for bid orders which are executed within the 120 minute interval and $\Delta P^{trade} = P_{t+\tau}^{MA} - P_t^{MA}$ for bid orders which are not executed within the interval. For ask orders, the corresponding values are $\Delta P^{trade} = P_t^{MB} - P_t^{LA}$ and $\Delta P^{trade} = P_t^{MB} - P_{t+\tau}^{MB}$ Significantly positive values of ΔP^{trade} will vindicate Silber's advice, significantly negative statistics will vindicate the strategy derived in this study for a risk neutral investor. A risk averse investor might still opt for $\tau' = 0$. even if $\tau' = 120$ offered higher returns since $\tau' = 120$ exposes the investor to a maximum of two hours of beneficial information risk, whereas $\tau' = 0$ does not. All observations in both the first and second halves of the database are tested and the results presented in Table 5.8 below.

The results in table 5.8 are quite straightforward. For limit orders which are executed within the 120 minute interval, ΔP^{trade} is negative by definition. For limit orders which are not executed within the 120 minute interval, it is seen that ΔP^{trade} is significantly positive. This accords with the information risks described: lack of execution is consistent with beneficial information arriving during the 120 minute interval and this will make the $t+\tau'$ market price less attractive than the market price at time t, resulting in a positive value of ΔP^{trade}. The key question is which of these two forces predominates: does the loss observed in unexecuted limit orders outweigh the gain from executed limit orders? The negative values in the final column show that it does not. Silber's rule (which is to be a price taker) results in a mean loss of 0.11 pence for stock orders ($t = -3.99$) and 0.85 index points for index orders ($t = -5.47$). All t statistics are significant at the 1% level, except for the Total Stock orders - second half of sample figure, which is significant at the 5% level. However, since the $\tau' = 120$ strategy involves greater risk than the $\tau' = 0$ strategy, investor utility functions cannot be dismissed as they were with Tables 5.6 and 5.7.

	Limit orders executed within 120 minutes			Limit orders not executed within 120 minutes			Total			
	n	Mean ΔP^{trade}	*t*	n	Mean ΔP^{trade}	*t*	n	Mean ΔP^{trade}	σ	*t*
Full sample	1,664	-2.5361	*-44.47*	3,276	0.7028	*8.64*	4,940	-0.3882	4.30	*-6.33*
First half of sample	944	-2.1446	*-43.10*	1,649	0.6756	*8.77*	2,593	-0.3511	2.99	*-5.99*
Second half of sample	720	-3.0490	*-27.30*	1,627	0.7300	*5.07*	2,347	-0.4290	5.40	*-3.85*
Stock orders	651	-1.5876	*-38.65*	2,428	0.2887	*10.52*	3,079	-0.1080	1.50	*-3.99*
Index orders	1,013	-3.1456	*-37.22*	848	1.8890	*6.28*	1,861	-0.8520	6.72	*-5.47*
Stock orders- first half of sample	384	-1.6250	*-29.20*	1,223	0.3299	*8.30*	1,607	-0.1372	1.56	*-3.52*
Index orders - first half of sample	560	-2.5009	*-35.27*	426	1.6680	*6.18*	986	-0.7000	4.39	*-5.01*
Stock orders - second half of sample	267	-1.5337	*-25.49*	1,205	0.2469	*6.53*	1,472	-0.0761	1.43	*-2.04*
Index orders- second half of sample	453	-3.9430	*-24.67*	422	2.1110	*3.91*	875	-1.0230	8.62	*-3.51*

Table 5.8: Mean values of the difference between the $\tau' = 0$ and the $\tau' = 120$ minutes strategies

Nevertheless, Silber's [1988] assertion can be rejected with confidence. The mean gains from the $\tau' = 120$ strategy shown in Table 5.8 amount to £1.08 per contract for stock options and £8.52 per contract for index options. These figures represent respectively 0.6% and 2.1% of the mean $\tau' = 120$ transactions price. Returns of this order, as a reward for no more than 120 minutes of beneficial information risk, will appeal to at least some of the retail investors on LIFFE, since over a suitably large portfolio of limit orders, investors could expect a mean gain with the $\tau' = 120$ strategy with more than a 99% probability. Sample selection bias can be rejected for this test, since the strategy is derived from the first half sample only and significantly negative values of ΔP^{trade} are found in the second half sample.

5.6 CONCLUSION

The act of placing a limit order grants an option to the marketplace at large. The granting of any option involves an assumption of risk, since the option is exercised at the taker's discretion and the taker's interests will generally be opposite to those of the grantor. In this paper, it is found that limit order investors appear to be particularly hampered by beneficial information preventing the execution of their orders. Two classes of limit order are identified, competing and monitoring. On LIFFE, monitoring orders represent only a small proportion of limit orders.

For competing orders, a simple limit order strategy is proposed, calling for investors to withdraw limit orders if unexecuted after 120 minutes and to trade at the market price prevailing at the end of that interval. *Ex ante* tests show this to be significantly (1%) better than observed practice for stock options, although not significantly so for index options, whose greater liquidity gives them rather different characteristics. It is also shown that this strategy offers significantly (1%) greater returns for both stock and index options than the advice given by Silber [1988] that retail investors should not attempt to compete with marketmakers, although it is recognised that this strategy exposes the investor to a maximum of 120 minutes of beneficial information risk which is avoided by those who follow Silber.

The strategy is derived and tested under weak assumptions: one of these is that the implementation of the strategy will not affect the bid-ask quotes observed in the marketplace. It is recognised that this assumption is good only for the marginal investor and would not hold if the strategy were implemented widely. In the tests, the strategy works because a significant proportion of limit orders are currently executed within a short interval of order placement. However, it would not take long for market participants to recognise the proposed strategy if it were implemented widely, and to introduce retaliatory action. It would be irrational for them to execute a limit order when they had reason to believe that the limit order would be withdrawn and substituted by a market order within two hours. Indeed, they would then be motivated to move the market quote firmly against the limit order investor.

The Public Limit Board on LIFFE is not used very actively. In the databases, executed limit orders account for only 3,085 of the 71,928 transactions observed (4.3%). The gains shown in this chapter justify greater usage. There remains further research to be undertaken. In particular, this study has not been able to determine optimum levels at which to enter limit prices; within the sample and under the assumptions presented, the gains appear to be homogeneously distributed across all levels of target spread capture. Larger samples and/or stronger assumptions may shed further light on this important question.

Nevertheless, retail investors are advised to attempt to compete with marketmakers by submitting limit *bid* orders below the prevailing market ask and limit *ask* orders above the prevailing market bid for individual stock options. If these are not executed within 120 minutes, the limit orders should be withdrawn and transactions undertaken at market prices. On the evidence of this paper, the probability of execution within the 120 minute interval exceeds 0.2 for stock orders and 0.5 for index options. The mean gains from these executions outweigh the mean losses from adverse changes in the market prices for orders which are not executed.

Appendix 5A: EXTRACT FROM PUBLIC LIMIT ORDER DATABASE FOR 10 JULY 1992

Time	Stock	Expiry	Exercise	Class	Bid volume	Bid price	Ask volume	Ask price
08:44:25.80	SEI	JUL92	02500	P	10	20.0		
08:49:00.10	ANL	SEP92	00280	C	3	8.0		
08:49:55.09	NPW	SEP92	00235	P	25	4.5		
08:52:35.75	ASD	OCT92	00035	P			10	9.5
09:00:01.06	NPW	SEP92	00235	P	20	5.5		
09:01:23.05	SEI	JUL92	02450	C			2	64.0
09:09:56.71	CUA	JAN93	00500	P			3	46.0
09:20:03.36	SEI	JUL92	02500	P			1	26.0
09:22:17.08	SEI	SEP92	02550	C	7	50.0		
09:26:07.77	SEI	JUL92	02450	P			10	10.0
09:28:47.23	SEI	JUL92	02500	C			3	15.0
09:30:33.60	SEI	JUL92	02550	P			10	64.0
09:32:07.74	GM	OCT92	00475	C			5	25.0
09:37:08.65	BP	JUL92	00220	P			8	17.0
09:40:51.12	EAE	FEB93	00280	C			7	24.0
09:42:13.35	SEI	JUL92	02500	P			10	24.0
09:42:36.98	BBL	SEP92	00330	C	20	6.0		

Chapter 6

INTRADAY QUOTED AND EFFECTIVE SPREADS ON FT-SE 100 INDEX OPTIONS

6.1 INTRODUCTION

The bid-ask spread on financial assets has been the subject of extensive research, both theoretical and empirical, for at least three decades. In more recent years, increasing attention has been given to the intraday behaviour of securities prices (*e.g.* Admati and Pfleiderer [1988] and [1989], Stephan and Whaley [1990], Porter [1992], Sheikh and Ronn [1994] *inter alia*).

The objective of the present chapter is to discover whether or not intraday patterns exist in the quoted and effective bid-ask spreads on the American style FT-SE 100 index options traded on the London International Financial Futures and Options Exchange (LIFFE) and to test for conformity with theoretical predictions. The distinction between quoted and effective spreads is made possible by the use of observed transactions prices alongside contemporaneous bid-ask quotes. A number of discrepancies from theoretical predictions are found: it is argued that these discrepancies arise principally because the classification of orders into informed and liquidity trades, which lies at the heart of much of the theory, is inappropriate for index options.

The chapter is organised as follows: Section 6.2 reviews relevant literature. The database and methodology used in the analysis is presented in Section 6.3, followed by the results and a discussion of the results in Sections 6.4 and 6.5 respectively. Section 6.6 concludes.

6.2 REVIEW OF LITERATURE

In order to provide the theoretical background to the analysis, a brief summary of the nature of the bid-ask spread is presented, followed by a review of the theoretical and then the empirical literature of the intraday behaviour of securities markets. Whilst the importance of the bid-ask spread on traded options has long been recognised, *e.g.* Phillips and Smith [1980], there is little literature devoted specifically to the subject.

Demsetz [1968, p36] defines the bid-ask spread as a "markup that is paid for predictable immediacy of exchange in organized markets." A considerable literature has developed this view over the years. The asymmetric information model of the bid-ask spread, as described in Glosten and Harris [1988], can be summarised thus: first consider a marketmaker in a competitive environment facing homogeneously informed investors. The equilibrium price charged for immediacy services will cover clearing costs and inventory costs and provide a fair return for the marketmaker's capital and labour. There is a risk inherent in holding inventory and the reward for this can be ascribed either to the inventory holding costs or to the fairness of the return to the marketmaker[1]. Now consider the presence of a number of better informed investors in such a market. The equilibrium price for immediacy services must be increased to enable the losses made from informed investors to be offset by extra gains made from uninformed investors.

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[1]Glosten and Harris [1988] also discuss returns to specialist monopoly power, but that is irrelevant to the present study, since the market studied is a competitive dealer market.

Admati and Pfleiderer [1988] consider the intraday pattern of trading volumes and price variability. Distinguishing between informed and liquidity traders, they argue that liquidity traders, to the extent that they have any discretion over the timing of their transactions, will choose to trade in thick trading periods, *i.e.* periods in which their transactions will have least price impact. Thus liquidity trading tends to become concentrated in one or more intervals. During these periods of concentrated liquidity trading, informed traders are also likely to trade more actively, so the prices observed during these periods of concentration are more informative than prices observed at other times. In this model, the variability of price changes is higher and transactions costs lower during these periods of concentrated trading than during other periods.

In a subsequent paper, Admati and Pfleiderer [1989] develop a model in which marketmakers induce separation of buy and sell orders by setting an asymmetric bid-ask spread around an equilibrium price. Thus, at times when the ask price is relatively close to the equilibrium price and the bid price relatively distant from it, a concentration of buy orders will be induced, and a concentration of sell orders will occur when the spread is set the other way. In this model, the marketmakers' adverse selection problems will be reduced, since the time-separation enables a more efficient identification of the probability of an informed trade (for example, a sell order arising during periods of liquidity purchases has a greater probability of being an informed trade) and marketmakers can adjust prices accordingly.

Foster and Viswanathan [1990] present a model similar to that of Admati and Pfleiderer [1988] but with a key difference. In the Admati and Pfleiderer [1988] model, the concentration of orders leads to lower transactions costs. Liquidity and informed traders trade alongside each other and competition among informed traders keeps transactions costs low. Thus the Admati and Pfleiderer model is characterised by periods of high volume, high volatility and low transactions costs. By contrast, Foster and Viswanathan [1990] present a model in which liquidity traders with discretion over the timing of their transactions delay trading in order to follow a wave of informed trading. Thus the high volume periods are associated with a high level of informed trading and a lower level of liquidity trading than is predicted by Admati and Pfleiderer [1988]. Hence marketmakers need to increase the adverse selection component of the bid-ask spread during such periods, leading to high transactions costs associated with periods of informed trading.

An empirical comparison of the Admati and Pfleiderer [1988] and Foster and Viswanathan [1990] models is conducted in Foster and Viswanathan [1993]. An analysis of transactions data for sixty NYSE traded stocks lends some support to the latter model, since the adverse selection costs appear to be higher at times of higher trading volume.

Lehmann and Modest [1994] find a U-shaped pattern for the intraday behaviour of bid-ask spreads on the Tokyo Stock Exchange and state (p964) "The U-shaped pattern of bid-ask spreads has been documented in virtually all market microstructure studies, regardless of the underlying instrument or country in which the market exists." They recognise the existence of exceptions to this general rule, but state (p 965) "We are not aware of any study that does not find spreads largest at the morning open".

One exception to the U-shaped rule is Mayhew [1993], who studies options traded on the Chicago Board Options Exchange (CBOE) and finds spreads widest at the opening of the market and then narrowing during the course of the day.

Stephan and Whaley [1990] study the lead-lag relationship in both price change and trading volume between stock and options markets. They observe that the stock market appears to lead the options market in respect of price changes by up to 15 minutes and by even longer in respect of trading volume. In both markets, they also find a U-shape for trading volumes, with a peak in volume at or near the opening of the day and a slightly lower peak at or near market close. The extent of the mid-day decline in trading volume is greater in the stock market than in the options market.

Porter [1992], in an empirical study of US and Canadian stock exchanges, looks for a bias in bid- or ask-side transactions at different times of the day. He finds a bias for ask-side transactions at the closing period for both Canadian and US exchanges. For the opening period, he finds a bias towards bid-side transactions on the Canadian exchange, but a bias towards ask-side transactions on the US exchanges. Other than these opening and closing periods, there was no significant bid- or ask-side bias during the day

Brock and Kleidon [1992] consider the effect on bid and ask prices of overnight market closure. They argue that the discontinuity of the market leads to strong and inelastic demand to trade both at the open and at the close of the market, with a consequent increase in ask prices and decrease in bid prices[2]. This leads to a situation in which increased transactions volume is matched by wider spreads, whereas it might otherwise be expected that increased transactions volume would be matched by narrower spreads, since in the asymmetric information model described earlier, one of the elements of the spread is the cost and risk of holding inventory, which should be reduced by increased trading volumes.

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[2]Brock and Kleidon [1992] emphasise the separate bid and ask prices as their primary economic variables: that the bid-ask spread widens as a result is regarded by them as a secondary effect.

Sheikh and Ronn [1994] analyse the daily and intraday returns on a sample of stock options traded on CBOE. They find that the variance of returns on the options follows a U-shaped pattern similar to the variance of returns on the underlying stocks, with peaks at the opening and close of the day. Furthermore, after adjusting the variance of returns on the options to remove the effect of the U-shaped variance of returns on the underlying stocks, the variance of returns on the options still shows a U-shape. This U-shape is also similar to the pattern of trading volume found in the stock and options markets by Stephan and Whaley [1990] and Foster and Viswanathan [1993]. The coincidence of volume and variance U-shapes is in line with the theoretical model of Admati and Pfleiderer [1988] which predicts a positive relationship between variance and volume. Sheikh and Ronn also find positive mean day-end returns for the stocks, reflected in a positive mean day-end return for the observed call options, but not reflected in a negative day-end return for the put options.

6.3 DATABASE AND METHODOLOGY

Database

The database used in this study comprises the American index options from the database described in Section 1.4. It is necessary to classify each transaction according to whether it occurs on the ask or the bid side of the spread. A number of transactions occur at the mid-point of the quoted spread and these are eliminated from the database. Table 6.1 below gives a breakdown of the remaining transactions.

	Bid	Ask	Total
Calls	6,468	6,422	12,890
Puts	7,261	7,539	14,800
Total	13,729	13,961	27,690

Table 6.1: Breakdown of transactions in database

These observations embrace 9 maturities from July 1992 to February 1993 and also June 1993 and 20 exercise prices from 2050 to 3000. With put and call classes available, this gives a possible 360 options series available for analysis, but not all the maturities have transactions in all the exercise prices and the database used contains 234 different options series.

Methodology

The database contains information for 96 consecutive trading days. Each day is divided into 16 half hour intervals, from 08.30 until 16.30. The following analyses are undertaken on the database:

i. The mean return and standard deviation of the underlying index for each half hour interval,

ii. The mean volume of option trading observed in each interval,

iii. The mean quoted and effective spreads for each interval,

iv. The mean change in the quoted and effective spreads of observed options series between pairs of intervals,

v. The mean change in transactions prices of observed options series between pairs of intervals,

vi. A test for runs of bid- or ask-side transactions over the period sampled, and

vii. A test for bid- or ask-side bias during the individual intervals.

i. The mean return and standard deviation of the underlying index for each half hour interval

A preliminary analysis is undertaken of the mean return and standard deviation of the index over each half hour interval.

ii. The volume of option trading observed in each interval

The next stage is to consider the volume of option trading in each interval, noting that the first and last intervals are truncated, since option trading does not commence until 08.35 and the market officially closes at 16.10, although the closing process may elicit trades occurring a few minutes after the official close. The database used does not provide details of transaction sizes. The frequency of trades in each interval is used as a proxy for the volume of trading.

iii. The mean quoted and effective spread for each half hour interval

Casual empiricism indicates the existence of a positive, but non-linear, relationship between the value of an option and the absolute size of its quoted bid-ask spread. Similarly, there appears to exist a negative, but non-linear, relationship between the value of an option and the proportional size of the quoted bid-ask spread. These are shown in Figure 6.1 below, which shows the absolute and proportional quoted spreads at market close for July Calls on 1 July 1992.

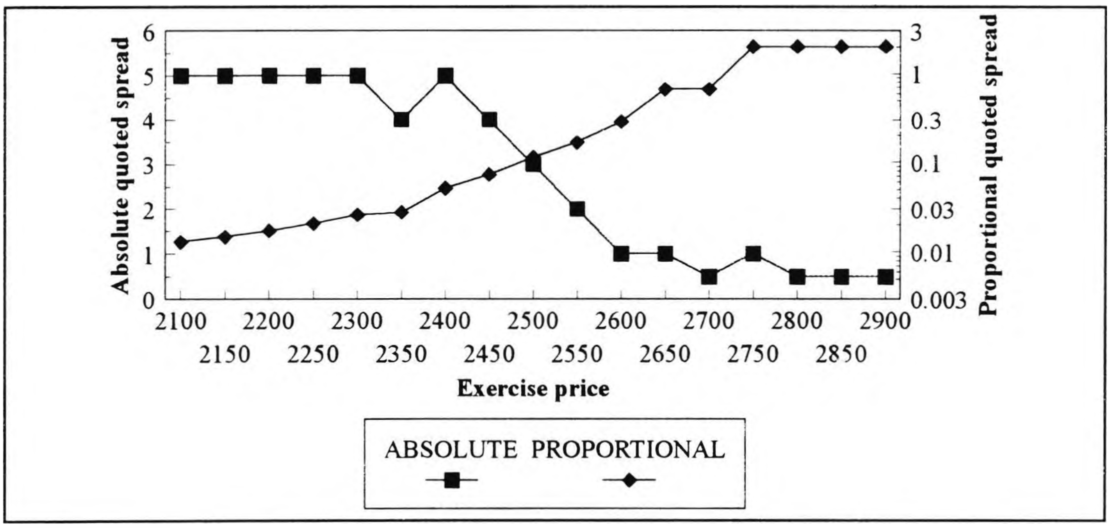

Figure 6.1: Absolute and proportional quoted bid-ask spreads for July Call options during the closing rotation on 1 July 1992. The 16.10 index level was 2490.2.

Figure 6.1 shows an essentially flat spread of 5 index points for the in the money options, falling by 1 index point per 50 points of exercise price for the near the money options and settling at ½ index point for the out of the money options.

It is therefore not possible merely to measure the mean size (absolute or proportional) of the spread in a given 30 minute interval, and compare it with the mean size in other intervals, because the results will be biased by the mixture of options traded. An interval containing a high proportion of deep in the money options will show a high mean value for the absolute size of the quoted spread and a low proportional value, whereas an interval with a high proportion of out of the money options will show the reverse. In such a case, comparison of the mean spreads quoted in the two intervals is meaningless.

Nevertheless, a preliminary overview of the issue can be obtained by allocating observations to portfolios separated by transactions price and then observing the mean quoted and effective spreads for each interval for each portfolio. The quoted spread at time t, Q_t, is defined as the difference between the quoted ask and bid prices, P_t^{ask} - P_t^{bid}. In order to define the effective spread, I_t, the assumption is made that a quote given by the crowd reflects a symmetric charge for immediacy services around an equilibrium midprice. It follows that the price paid for immediacy services is defined as the difference between the midprice and the transactions price, *ie* $I_t = P_t^{trade} - P_t^{mid}$ for ask side transactions and $I_t = P_t^{mid} - P_t^{trade}$ for bid side transactions. This definition of I_t is one half of the definition of the effective spread adopted by Petersen and Fialkowski [1994], who assume that a price improvement achieved on one side of the spread could be matched by an equal price improvement on the other side. Their assumption seems questionable and is unnecessary in the present study, which analyses only observed rather than assumed price improvements.

For the purpose of this analysis, the proportional quoted (Q_t^{pro}) and effective (I_t^{pro}) spreads analysed are defined as:

$$Q_t^{pro} = \frac{Q_t}{P_t^{mid}} \tag{6.1}$$

$$I^{pro} = \frac{I_t}{P_t^{trade}} \tag{6.2}$$

Observations are allocated to one of ten price portfolios by transactions price and the mean quoted and effective bid-ask spreads, absolute and proportional, are calculated for each portfolio for each of the 16 intervals. Price intervals of 10 points are used for portfolio definition and, for this test, observations of transactions prices in excess of 100 points are omitted, to avoid small sample sizes. This filter removes 3,308 observations (12%).

iv. The mean change in the quoted and effective spreads of observed options series between pairs of intervals

The principal analyses in this chapter are of the changes in the quoted and effective spread during the day. The distinction between the two is necessary because almost 40% of the transactions observed in the database occur at prices within the bid-ask spread quoted immediately prior to the transaction.[3]

[3]Petersen and Fialkowski [1994] describe how posted bid-ask quotes on the NYSE may not accurately reflect the best available prices: for example small limit orders which would better standing quotes may not be displayed. This is not the case on LIFFE; quoted prices reflect the best from all announced bids and offers. Transactions inside the quoted spread may occur because the broker manages to negotiate a finer price for a given transaction or because a given transaction in a series may form part of a combination of orders. A vertical bull spread, for example, (long call, short further out of the money call), limits the risk shouldered by the marketmaker and competition for the order should narrow the effective spread from that charged for two separate transactions.

The portfolio approach described above in point *iii.* is insufficiently robust for detailed analysis of the intraday behaviour of the spreads, because the aggregation into portfolios by price brings together options with heterogeneous characteristics. For example, the portfolio comprising the transactions price range 30.5 to 40 might contain a number of highly liquid, at the money, short dated options, as well as some highly illiquid, long-dated, out of the money options. The different liquidity and risk attributes of these two types of option make it unjustifiable to assume *ex ante* that the intraday spread behaviour of these two options will be the same.

To overcome this problem, an analysis of the ***change*** in the quoted and effective spreads is undertaken, rather than an analysis of their absolute or proportional sizes. For each observed transaction, the two parameters, Q_t (absolute quoted spread) and I_t (absolute effective spread), are measured. The database is then searched for transactions involving the same options series on the same side of the spread occurring on the same day in each subsequent half hour interval to that in which the observed transaction took place. Where an observation matching these criteria is found, the corresponding parameters Q_j and I_j are noted. (The subscript j represents the end of the half hour interval, 9.30, 10.00,..16.30, in which the subsequent transaction is observed).

This study is concerned with the change in the parameters Q_t and I_t during the course of the day. The tests conducted are therefore of the statistics $\Delta Q_{i,j}$ and $\Delta I_{i,j}$ when $\Delta Q_{i,j} = Q_i - Q_j$ and $\Delta I_{i,j} = I_i - I_j$; the subscripts i and j represent the end of one of the half hour intervals (9.00, 9.30,...16.30), subject to the condition $i < j$[4]. Since there are 15 intervals i and 15 intervals j and the condition $i < j$ is imposed, it will be seen that there are 120 qualifying pairings of i and j. If the quoted spread widens between interval i and interval j, $\Delta Q_{i,j} < 0$, whereas if it narrows, $\Delta Q_{i,j} > 0$. Similarly, if the effective spread in a subsequent interval j is greater than that in interval i, $\Delta I_{i,j} < 0$, whereas if it decreases between the intervals, $\Delta I_{i,j} > 0$.

[4]This condition is imposed because it is reasonable to assume an investor is capable of delaying a trade, but it may not be justifiable to assume that an investor can bring a trade forward.

The tests are thus of the null hypotheses that the mean values of $\Delta Q_{i,j}$ and $\Delta I_{i,j}$ are zero for each pair of intervals, $i < j$. There are no substantive grounds to assume *ex ante* that the values of $\Delta Q_{i,j}$ and $\Delta I_{i,j}$ will be normally distributed, but a Shapiro-Wilk test shows *ex post* that these distributions are approximately normal, so a t test is used for the null hypotheses.

The procedure described above ensures that like is compared with like, but two possible sources of bias remain. First, since the analysis takes place over a period of time, market drift must be recognised. An out of the money series, with a transaction observed during the first interval, may become an in the money option, with a correspondingly wider quoted spread at the end of the day. This possible bias is recognised but discounted: the indications from Figure 6.1 are that where the spread widens in response to moneyness, it appears to do so at a rate of approximately 1 index point per 50 points of market drift, so that only an unusually large index movement will have any effect.

The second potential bias comes from the use of the absolute size of the change in the spread rather than the proportional size. This means that equal weight is given to a ½ index point change in the spreads of deep in the money options, where such a change represents about 10% of the typical spread, and far out of the money options, where such a change represents up to 100%. The alternative is to use a proportional measure, but this would suffer from the converse problem. Excessive weight would be given to small changes in the spreads of far out of the money options. Furthermore, use of a proportional measure will generate a lot of noise in the data, because of the impact of market drift. For example, an option quoted at 9-11 in one interval and 10-12 later would be recorded as showing a quoted spread narrowing from 0.2 to 0.18 under a proportional measure, whereas it would be recorded as unchanged using an absolute measure. The proportional change would not be a function of any intraday factor, but merely a consequence of market drift. However, in recognition of the potential bias, the database is broken down into subsamples by moneyness to test for differences attributable to this factor.

v. *The mean change in transactions prices of observed options series between pairs of intervals*

Much of the theory of the intraday pattern of trades rests on the influence which informed traders have on the market. The following test has the objective of establishing whether or not specific intervals of the day are characterised by an incidence of informed trading. This should be evident from observed changes in transactions prices. Intervals with a high incidence of informed trading should be characterised by a high incidence of transactions at more favourable prices than are observed in other intervals. To test this, a third variable is analysed: the difference in transactions price between the pairs of intervals. $\Delta P_{i,j}^{trade}$ is defined as P_j^{trade} - P_i^{trade} for bid side transactions and P_i^{trade} - P_j^{trade} for ask side transactions. The difference in definition between bid and ask side transactions results in a consistent sign for the outcome of the analysis. A positive value of $\Delta P_{i,j}^{trade}$ indicates a more favourable price for the investor in interval j than in interval i, whereas a negative value indicates a more favourable price in interval i than in interval j. The forecasting ability of this variable is analysed by testing whether *ex post* analysis of the first half of the database can forecast *ex ante* significant values in the second half.

As an example of the preceding three analyses, Appendix 6A shows a complete record of Q_i, Q_j, I_i, I_j, $\Delta Q_{i,j}$, $\Delta I_{i,j}$ and $\Delta P_{i,j}^{trade}$ for the first observation in the database. This is a July 2500 Put on the ask side occurring at 08:38:33 on 1 July 1992. The index stood at 2529.3 and the market quote was 18-23. The trade took place at 22. Since the observation was in the first half hour, i = 9.00. Q_i (the quoted bid-ask spread), was 5 and I_i (transaction price minus the midpoint of the quoted spread) was 1.5. During the remainder of that day, there were ask-side transactions of the same series in intervals ending 9.30, 11.00, 11.30, 12.00, 12.30, 13.00, 13.30 and 15.30.

In each of these observations, the quoted spread was narrower than at the original observation and the transaction took place at the quoted ask price. Thus both $\Delta Q_{i,j}$ and $\Delta I_{i,j}$ are shown as positive in all cases, revealing that both the quoted and effective spreads were lower in all subsequent observations. Nevertheless, the investor who traded this first observation fared better than those who traded in subsequent intervals, since the underlying index fell sharply during the day and the price of the put option rose correspondingly ($\Delta P_{i,j} < 0$ in all cases). A record similar to Appendix 6A is created for each of the 27,690 observations in the database.

vi. A test for runs of bid- or ask-side transactions over the period sampled

Admati and Pfleiderer [1989] forecast the clustering of bid-side and ask-side orders. If this occurs, a non-parametric runs test will reveal the existence of longer, and hence fewer, runs than can be expected by chance. A runs test is undertaken for the total sample and for the subsamples of put and call options separately.

vii. A test for bid- or ask-side bias during the individual half hour intervals.

Porter [1992] finds bid- and ask-side biases at different times of the day in Canadian and US stock exchanges. For the market analysed in this study, a χ^2 test is undertaken of the null hypothesis that the proportion of ask side transactions is equal across all 16 intervals.

6.4 RESULTS

i. The mean return and standard deviation of the underlying index for each half hour interval

The results are presented in appendix 6B. The mean return in each interval is insignificantly different from zero in all intervals except the final two. The standard deviation of returns shows a marked peak in the first half hour, falling to a low point at lunchtime, increasing during early trading on the New York Stock Exchange (14.30 to 16.00 London time) and falling away again at the London close.

ii. The mean volume of option trading observed in each interval

These results are also presented in Appendix 6B. 30% of the transactions take place before 10.00. There is a close correlation ($R^2 = 0.759$) between the mean number of transactions and the standard deviation of returns in each interval. This is shown graphically in Figure 6.2 below.

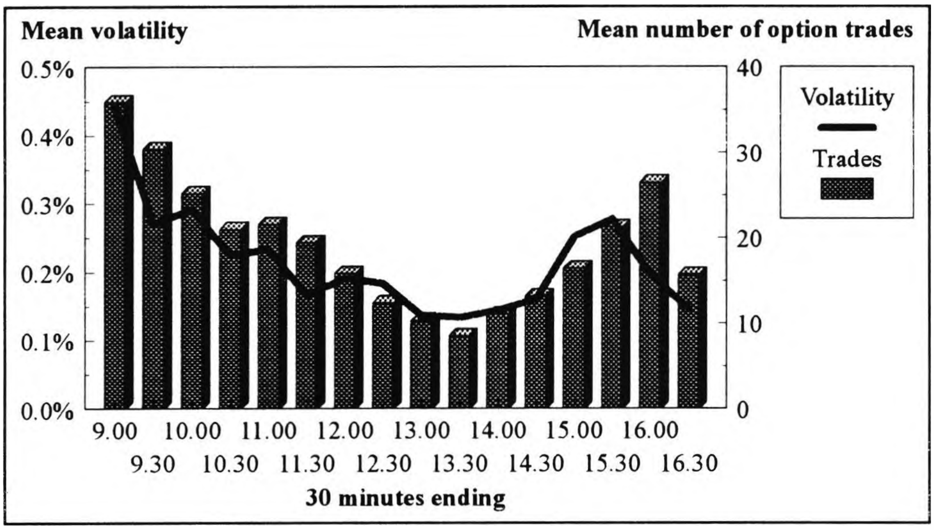

Figure 6.2: Mean number of option trades and standard deviation of index returns during each half hour interval

iii. The mean quoted and effective spread for each half hour interval

The results of this analysis are presented in Appendix 6C and shown graphically in Figures 6.3 and 6.4 below. Figures 6.3 and 6.4 show little systematic pattern to the behaviour of the spread during the day. The nearly ubiquitous U-shaped pattern described by Lehmann and Modest [1994] is absent and there is little support for even the more general rule that spreads are widest at the morning open. However, as discussed earlier, this analysis, which groups options by transactions price, regardless of moneyness and time to maturity, may be insufficiently precise to identify the fine detail of intraday patterns.

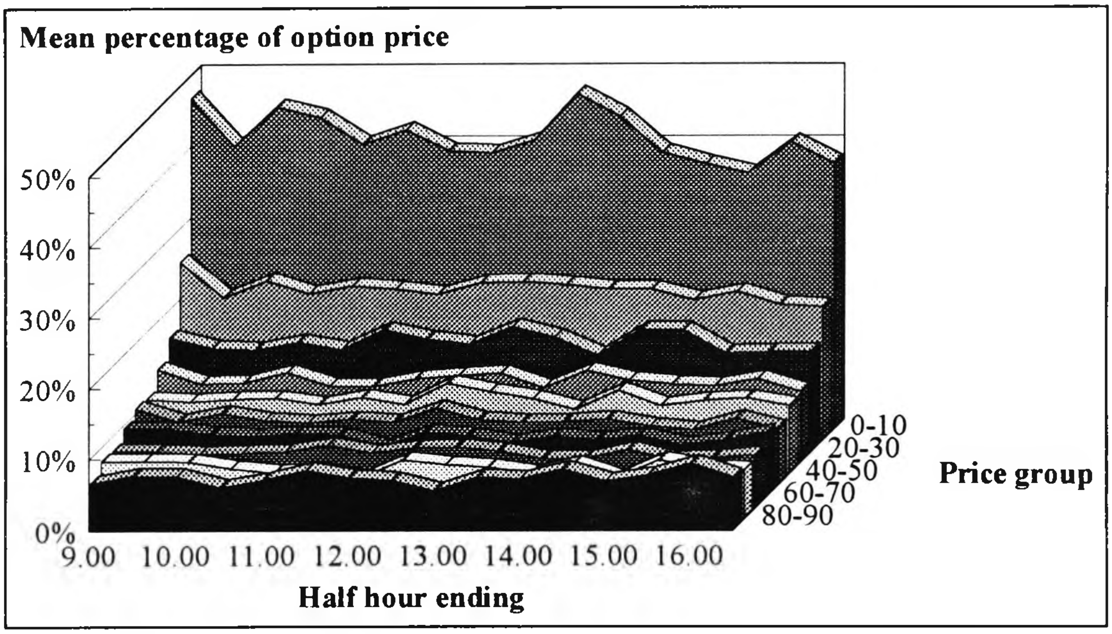

Figure 6.3: Mean value of proportional *quoted* spread by half hour interval and option transaction price

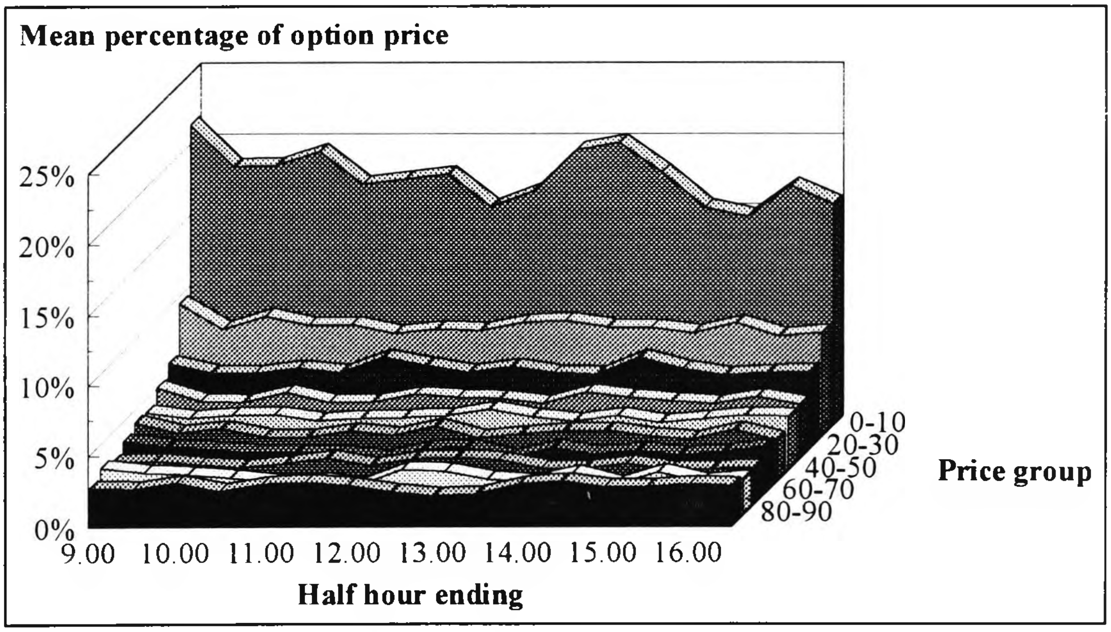

Figure 6.4: Mean value of proportional *effective* spread by half hour interval and option transaction price

iv. The mean change in the quoted and effective spreads of observed options series between pairs of intervals

This analysis overcomes the defects of the previous one by considering the intraday changes in the quotes of identically specified options. The mean values of $\Delta Q_{i,j}$ and $\Delta I_{i,j}$ are presented in Tables 6.2 and 6.3. The layout of the rows and columns in these tables enables easy analysis. A half hour interval which is more (less) expensive than *subsequent* intervals manifests itself with a *row* of significantly positive (negative) values. Similarly, a half hour interval which is more (less) expensive than *preceding* intervals manifests itself by a *column* of negative (positive) numbers.

Two key points are immediately apparent from Tables 6.2 and 6.3. First, all the mean values recorded for $i = 9.00$ (*i.e.* the first half hour interval) are significantly (5%) positive in both tables. This indicates that both the quoted and effective bid-ask spreads are higher in the first interval than in all subsequent intervals. This is similar to the finding of Mayhew [1993] who also studies an options market. It also conforms with the more general finding of Lehmann and Modest [1994] that spreads are widest at the opening across all markets and instruments in all studies of which they are aware. No other interval appears to be either significantly expensive or significantly cheap in respect of either $\Delta Q_{i,j}$ or $\Delta I_{i,j}$. The 9.00 interval is also notable in that, despite being only 25 minutes long, it accounts for almost 12% of the transactions observed.

Second, there is a conspicuous absence of negative values throughout both tables. Since the test is specified in such a way as to examine only trade delays rather than cases in which the transaction time is brought forward, there is an indication that such change as there is in the bid-ask spread during the day takes the form of a narrowing rather than a widening.

The times indicated in the row and column headings mark the end of the thirty minute intervals represented by i and j respectively. Mean values of $\Delta Q_{i,j}$ which are significantly (5%) different from zero are indicated in **bold type**. The mean sample size is 528 observations per (i, j) pairing with a maximum of 1,498 for the pair ($i = 9.00, j = 9.30$) and a minimum of 200 for the pair ($i = 13.00, j = 13.30$). The values are expressed in index points, which can be multiplied by £10 to give a monetary value per contract.

j / i	9.30	10.00	10.30	11.00	11.30	12.00	12.30	13.00	13.30	14.00	14.30	15.00	15.30	16.00	16.30
9.00	**0.739**	**0.800**	**0.458**	**0.610**	**0.897**	**0.543**	**0.775**	**0.827**	**0.800**	**0.518**	**0.948**	**0.712**	**0.831**	**0.756**	**0.606**
9.30		0.168	-0.099	0.035	0.162	0.071	**0.375**	0.143	0.275	0.298	0.118	-0.009	**0.393**	0.035	-0.050
10.00			**-0.227**	-0.033	0.240	-0.049	**0.415**	**0.336**	**0.515**	0.100	**0.320**	**0.329**	0.234	0.191	**0.370**
10.30				-0.079	-0.108	0.201	0.111	0.117	-0.005	-0.050	0.058	**0.397**	0.226	**0.289**	**0.384**
11.00					**0.264**	**0.238**	-0.034	0.079	-0.291	-0.049	0.170	0.210	**0.433**	**0.253**	0.255
11.30						0.161	**0.389**	**0.441**	0.373	0.247	0.314	**0.514**	0.211	0.125	0.233
12.00							**0.437**	**0.458**	0.321	0.191	0.074	0.094	**0.355**	0.018	0.165
12.30								0.200	0.036	0.343	0.123	-0.121	**0.424**	0.102	-0.199
13.00									0.373	-0.096	0.224	0.108	**0.432**	0.217	-0.048
13.30										**0.468**	0.071	0.438	0.326	0.241	0.165
14.00											-0.041	-0.205	0.022	-0.151	-0.084
14.30												0.220	0.246	-0.158	-0.270
15.00													0.057	-0.197	-0.047
15.30														-0.086	-0.187
16.00															-0.127

Table 6.2: Mean values of $\Delta Q_{i,j}$ for the full sample

The times indicated in the row and column headings mark the end of the thirty minute intervals represented by i and j respectively. Mean values of $\Delta I_{i,j}$ which are significantly (5%) different from zero are indicated in **bold type**. The mean sample size is 528 observations per (i, j) pairing with a maximum of 1,498 for the pair (i = 9.00, j = 9.30) and a minimum of 200 for the pair (i = 13.00, j = 13.30). The values are expressed in index points, which can be multiplied by £10 to give a monetary value per contract.

j / i	9.30	10.00	10.30	11.00	11.30	12.00	12.30	13.00	13.30	14.00	14.30	15.00	15.30	16.00	16.30
9.00	**0.370**	**0.378**	**0.360**	**0.330**	**0.408**	**0.225**	**0.377**	**0.446**	**0.419**	**0.332**	**0.370**	**0.274**	**0.383**	**0.309**	**0.383**
9.30		0.051	-0.055	0.027	0.038	-0.068	0.096	**0.165**	0.058	-0.036	-0.012	0.012	**0.152**	0.012	-0.025
10.00			-0.022	**0.121**	0.062	-0.112	**0.237**	**0.164**	0.028	0.003	0.091	0.058	0.037	0.059	0.056
10.30				-0.007	0.002	-0.031	**0.151**	-0.003	-0.097	0.013	0.034	0.088	0.071	0.087	0.027
11.00					0.078	0.044	0.029	**0.151**	-0.007	-0.061	-0.075	-0.003	**0.175**	0.034	0.008
11.30						-0.053	0.086	0.142	0.111	0.059	0.049	0.092	**0.129**	-0.065	-0.057
12.00							**0.190**	**0.185**	0.118	0.078	-0.035	0.103	**0.167**	-0.002	0.018
12.30								-0.028	-0.052	0.045	-0.079	**-0.216**	0.131	**-0.229**	**-0.268**
13.00									0.086	-0.060	-0.013	-0.065	0.051	-0.102	0.044
13.30										0.035	-0.088	-0.020	0.024	-0.051	-0.111
14.00											0.034	-0.012	-0.041	**-0.144**	-0.091
14.30												**0.188**	0.086	-0.100	**-0.198**
15.00													-0.055	**-0.115**	-0.120
15.30														-0.078	-0.100
16.00															-0.030

Table 6.3: Mean values of $\Delta I_{i,j}$ for the full sample

The markedly systematic results for the i = 9.00 row and the unsystematic nature of the results for the other rows merit further examination. The sample is therefore broken down into subsamples of ask and bid side transactions, put and call options, near dated (expiry ≤30 days) and medium dated (31 days ≤ expiry ≤ 60 days) options and five classes of moneyness ($-5 \leq m < -2$, $-2 \leq m < -0.5$, $-0.5 \leq m < 0.5$, $0.5 \leq m < 2$ and $2 \leq m < 5$, where $m = 100(S/X - 1)$ for calls and $100(1 - S/X)$ for puts). For each of these subsamples, matrices of mean values of $\Delta Q_{i,j}$ and $\Delta I_{i,j}$ are calculated. They generally show a pattern very similar to those found in the total sample, namely a high incidence of significantly positive values for the i = 9.00 row and an unsystematic distribution of principally positive values for the other rows. This is less apparent in the medium dated and deep in the money subsamples, because small sample sizes lead to a dearth of significant values. Rather than overburden the paper, Appendices 6D and 6E present only the i = 9.00 results for $\Delta Q_{i,j}$ and $\Delta I_{i,j}$ respectively for each of the subsamples tested.

Thus the interval ending 9.00 appears to have characteristics significantly different from the other intervals. It is therefore natural to scrutinise this interval, by dividing it into smaller intervals. Since trading does not commence until 8.35, this more detailed analysis divides the interval into five subintervals, each of five minutes. The intervals each have approximately 640 transactions. The same test procedure is used, namely determining the mean values of $\Delta Q_{i,j}$ and $\Delta I_{i,j}$, except that in this case, i = 8.40, 8.45, 8.50, 8.55 and 9.00, whilst, as before, j = 9.30, 10.00... The results are presented in Table 6.4 below.

Table 6.4 shows that there is a systematic structure within the first twenty five minutes. The mean values of $\Delta Q_{i,j}$ and $\Delta I_{i,j}$, and the incidence of significance, are generally greatest for i = 8.40 and decrease with each succeeding interval. Thus the significance of the i = 9.00 row in Tables 6.2 and 6.3 appears to stem almost exclusively from the first ten minutes of trading.

The times indicated in the row and column headings mark the end of the five and thirty minute intervals represented by i and j respectively. Mean values of $\Delta Q_{i,j}$ and $\Delta I_{i,j}$ which are significantly (5%) different from zero are indicated in **bold type**. The mean sample size is 184 observations per (i, j) pairing with a maximum of 329 for the pair $(i = 8.50, j = 9.30)$ and a minimum of 83 for the pair $(i = 8.55, j = 13.30)$. The values are expressed in index points, which can be multiplied by £10 to give a monetary value per contract.

								$\Delta Q_{i,j}$							
i \ j	**9.30**	**10.00**	**10.30**	**11.00**	**11.30**	**12.00**	**12.30**	**13.00**	**13.30**	**14.00**	**14.30**	**15.00**	**15.30**	**16.00**	**16.30**
8.40	**1.5760**	**1.3700**	**0.7080**	**1.0020**	**1.3300**	**1.0700**	**1.3620**	**1.3740**	**1.4240**	**1.3900**	**1.4080**	**1.0580**	**1.4180**	**1.2240**	**1.1540**
8.45	**0.7180**	**0.8160**	**0.7680**	**0.9740**	**1.0520**	**0.7720**	**1.1440**	**1.0700**	**0.9120**	**0.4200**	**1.4820**	**0.8960**	**1.0540**	**0.9980**	**0.9720**
8.50	**0.5502**	**0.6250**	**0.4012**	0.2456	**1.0504**	**0.8154**	**0.8300**	**0.6510**	**0.7992**	0.4688	0.5070	0.3944	**1.0642**	**1.0914**	0.3814
8.55	0.2916	**0.7430**	0.2790	0.3774	**0.9764**	0.3152	0.2276	0.2894	0.3856	0.3268	**0.5902**	**0.7418**	**0.7420**	0.2536	0.4666
9.00	**0.5592**	**0.4576**	0.0910	**0.4682**	0.0240	-0.3892	0.2056	**0.7170**	0.2678	-0.0082	**0.6846**	0.4148	-0.1744	0.1152	-0.0332
								$\Delta I_{i,j}$							
i \ j	**9.30**	**10.00**	**10.30**	**11.00**	**11.30**	**12.00**	**12.30**	**13.00**	**13.30**	**14.00**	**14.30**	**15.00**	**15.30**	**16.00**	**16.30**
8.40	**0.8780**	**0.6680**	**0.7800**	**0.6320**	**0.7440**	**0.4960**	**0.6500**	**0.7650**	**0.5330**	**1.1020**	**0.5240**	**0.5510**	**0.6240**	**0.5700**	**0.7960**
8.45	**0.3297**	**0.3342**	**0.4370**	**0.4852**	**0.4309**	0.2286	**0.4554**	**0.5211**	**0.4301**	0.1535	**0.5151**	**0.3376**	**0.3643**	**0.2795**	**0.3556**
8.50	**0.3024**	**0.2644**	0.1483	0.0302	**0.4454**	**0.3821**	**0.3550**	0.3183	**0.4423**	0.1649	**0.2710**	0.1018	**0.4874**	**0.4827**	**0.3997**
8.55	0.0878	**0.3900**	0.2079	0.2212	**0.3971**	0.1395	0.1942	0.3070	**0.4277**	**0.2972**	0.1230	0.1748	**0.3118**	0.0471	0.2111
9.00	**0.2500**	**0.2542**	**0.2554**	**0.3083**	0.0279	-0.1409	0.1996	**0.3160**	0.2173	-0.0081	**0.3758**	0.1720	0.1179	0.1359	0.1060

Table 6.4: Mean values of $\Delta Q_{i,j}$ and $\Delta I_{i,j}$ for the subintervals of the first 25 minutes

v. The mean change in transactions prices of observed options series between pairs of intervals

This test searches for evidence of informed trading. $\Delta P_{i,j}^{trade}$ is defined such that positive values indicate more favourable trading prices in interval *j* than in interval *i*, and negative values indicate the reverse. Informed traders will generally trade at relatively favourable prices, and the values of $\Delta P_{i,j}^{trade}$ are therefore used as an indication of informed trading. The mean values of $\Delta P_{i,j}^{trade}$ are presented in Table 6.5 below. Intervals *i* with favourable transactions prices are indicated by a row containing a high incidence of significantly negative values and intervals *j* with favourable transactions prices are indicated by columns with a high incidence of positive values, whilst opposite signs indicate the presence of unfavourable trading prices.

There is no very systematic pattern in this variable. The row *i* = 9.00, which gave such consistent results in Tables 6.2 and 6.3, is less consistent in this case. Seven of the fifteen values are significantly positive and only one significantly negative. The magnitude of the positive values of $\Delta P_{i,j}$ in this row exceed the equivalent magnitudes of $\Delta I_{i,j}$, so it could be inferred that investors at the start of the day not only pay more for immediacy services than in other intervals, but also appear to be significantly ill-informed about the short term movement of the market. Caution about such an inference should however be drawn from the lower part of Table 6.5 which shows an unsystematic distribution of values when the *i* = 9.00 row is broken down into five minute intervals.

Other conspicuous features of Table 6.5 are the cluster of significantly negative values at the bottom of the columns *j* = 13.00 and *j* = 13.30 and the group of significantly positive values at the top of the column *j* = 16.00. These could indicate that investors at lunchtime are significantly less informed than those in the late morning and that investors in the late afternoon are significantly better informed than those in the early and mid morning. However, it would be imprudent for a trader to develop a rule based on this evidence without testing its forecasting ability.

The times indicated in the row and column headings mark the end of the thirty minute (or five minute) intervals represented by i and j respectively. Mean values of $\Delta P_{i,j}$ which are significantly (5%) different from zero are indicated in **bold type**. The mean sample size for the upper part of the table is 528 observations per (i, j) pairing with a maximum of 1,498 for the pair (i = 9.00, j = 9.30) and a minimum of 200 for the pair (i = 13.00, j = 13.30). For the lower part, the mean sample size is 184 observations per (i, j) pairing with a maximum of 329 for the pair (i = 8.50, j = 9.30) and a minimum of 83 for the pair (i = 8.55, j = 13.30). The values are expressed in index points, which can be multiplied by £10 to give a monetary value per contract.

i \ *j*	**9.30**	**10.00**	**10.30**	**11.00**	**11.30**	**12.00**	**12.30**	**13.00**	**13.30**	**14.00**	**14.30**	**15.00**	**15.30**	**16.00**	**16.30**
9.00	**-0.411**	-0.312	**0.634**	0.500	**1.520**	**1.203**	**1.652**	**1.342**	-0.585	**1.256**	0.630	0.264	0.593	**1.366**	1.117
9.30		-0.209	0.125	-0.062	0.698	-0.354	-0.045	0.132	-0.372	0.704	0.235	0.556	0.858	**1.070**	0.727
10.00			0.150	0.262	**1.039**	-0.294	**1.105**	0.725	-0.646	**1.115**	**1.060**	0.699	0.055	**1.416**	**1.347**
10.30				-0.285	0.030	0.045	-0.584	-0.739	-0.925	0.732	**1.527**	0.881	0.384	**1.343**	-1.067
11.00					0.033	-0.142	-0.206	0.525	**-1.180**	0.187	0.363	0.722	0.483	0.604	0.087
11.30						-0.301	-0.561	**-1.254**	**-1.426**	0.643	0.034	0.009	**-1.380**	-0.068	-0.756
12.00							-0.285	**-0.968**	**-1.543**	-0.095	-0.486	-0.488	**-1.219**	-0.982	-1.038
12.30								**-0.717**	**-1.438**	-0.876	-0.682	-0.268	0.572	0.342	0.186
13.00									**-0.635**	-0.534	**-1.361**	-0.279	-0.380	**-1.352**	1.594
13.30										0.071	**-1.065**	-0.394	-0.123	-0.937	-0.202
14.00											**-0.535**	-0.363	0.085	**-1.138**	-0.078
14.30												-0.221	-0.025	-0.620	0.601
15.00													-0.130	-0.179	0.676
15.30														**-0.586**	0.425
16.00															0.431

i \ *j*	**9.30**	**10.00**	**10.30**	**11.00**	**11.30**	**12.00**	**12.30**	**13.00**	**13.30**	**14.00**	**14.30**	**15.00**	**15.30**	**16.00**	**16.30**
8.40	-0.3410	-0.8530	**2.4900**	1.0700	0.8010	**1.9750**	0.9960	0.9570	-1.1420	**2.0080**	-0.6600	-0.4130	-0.3300	**2.3020**	-0.9320
8.45	**-0.7360**	**-1.2820**	-0.5100	0.2840	1.6180	0.0120	**1.9530**	**2.3420**	0.1990	0.3420	0.8520	1.0590	1.1740	**1.8330**	**3.4670**
8.50	-0.4160	-0.2940	0.2580	0.0600	**1.8740**	**2.7950**	**2.3830**	**1.9640**	-1.2010	1.3960	1.1710	0.4120	1.1170	**1.9430**	0.7370
8.55	**-0.9540**	-0.1550	0.6550	-0.1680	0.7970	1.0220	2.0710	-0.4520	-1.5720	0.5750	-0.9670	-1.4930	-1.1180	-0.4010	-0.4930
9.00	0.3320	**1.2350**	0.6540	**1.2330**	**2.2710**	0.4360	0.7620	1.5330	0.8510	2.1870	2.2520	1.7520	1.7100	0.9400	2.3970

Table 6.5: Mean values of $\Delta P_{i,j}^{trade}$ for the full sample

This is undertaken in a similar manner to the *ex ante* test in Chapter 5. The database, which covers 96 trading days, is divided into two halves, using the market close on 7 September as the midpoint. The test is whether or not an investor at this time, looking back over the previous 48 trading days of data, could forecast intervals of significantly positive or negative values of $\Delta P_{i,j}^{trade}$ which would occur over the next 48 trading days.

Appendix 6F presents the mean values of $\Delta P_{i,j}^{trade}$ for the two different sample periods. Very little similarity is seen between the two sets of figures. Of the 21 significant values recorded in the early period, only two are similarly significant in the later period, whilst another two are significant, but with the opposite sign. The remaining 17 significant values in the early period are not significant in the later period. Thus the values of $\Delta P_{i,j}^{trade}$ appear to have no forecasting power at all. Table 6.5 and Appendix 6F are capable of many different interpretations: Occam's razor leads to an overall conclusion from them that no individual interval or subinterval shows a significant incidence of either informed or uninformed trading. This is discussed further in Section 6.5.

vi. *A test for runs of bid- or ask-side transactions over the period sampled*

Admati and Pfleiderer [1989] predict the existence of runs of bid- or ask-side transactions of greater length than can be expected by chance alone. Their theory is presented in terms of stock prices and there are arguments on both sides as to whether it should apply to the total options sample or merely to put and call classes separately. In support of treating all options together is the fact that long or short put positions can be constructed synthetically from long or short call positions and *vice versa*, so that the theory should apply to the whole sample. On the other hand, Chapter 3 indicates the existence of a clientele effect distinguishing between put and call options, in which case the two classes should be tested separately. In order to satisfy both sides, the entire sample is tested first and then the put and call classes are tested separately. A standard runs test is used and the results are presented in Table 6.6 below.

Sample	Number of asks	Number of bids	Expected number of runs	Standard deviation	Observed number of runs	Difference	*z*
Total	13,961	13,729	13,845	83.19	12,932	-913	*-10.97*
Calls	6,422	6,568	6,446	56.76	5,759	-687	*-12.10*
Puts	7,539	7,261	7,398	60.80	6,574	-824	*-13.55*

Table 6.6: Results of test for runs of bid- or ask-side transactions

Table 6.6 shows fewer, and hence longer, runs than expected at a high level of significance for the total sample and for the individual put and call samples. This is consistent with the model of Admati and Pfleiderer [1989].

vii. A test for bid- or ask-side bias during the individual half hour intervals

Given that runs of significant length exist, the question then arises as to whether or not individual intervals show a bid- or ask-side transactions bias. A χ^2 is undertaken of the null hypothesis that the proportion of ask side transactions is the same in each of the 16 intervals across the 96 day sample. Again, the test is undertaken first for the full sample and then for the put and call subsamples separately. The results are presented in Appendix 6G and it is seen that the values of the χ^2 variables are a long way below the 5% significance levels for 15 degrees of freedom. Therefore, it is concluded that there is no significant tendency for bids or asks to cluster at particular times of day.

6.5 DISCUSSION OF RESULTS

The results presented in the preceding section show partial consistency with and partial contradiction of the theories and empirical studies presented in the literature review. First, Brock and Kleidon [1992] predict, and Stephan and Whaley [1990] and Foster and Viswanathan [1993] find, U-shaped patterns in trading volumes, with high transactions demand at the opening and closing of the day. Figure 6.1 shows a near U-shape in trading volumes. The apparent shortfall in volume in the final interval should be discounted, since trading officially ceases after 10 minutes of this interval.

Next, the high correlation between trading volume and volatility is consistent with Admati and Pfleiderer [1988]. However, those authors forecast that periods of high volume and volatility will be matched by low transactions costs in the form of a narrow bid-ask spread, whereas the results in Tables 6.2 and 6.3 show that the interval with the highest volume and volatility, $i = 9.00$, also has the highest quoted and effective bid-ask spreads.

The existence of the widest spreads during the first session of the day accords with the findings of Mayhew [1993] in another study of an options market and with the point in the review of studies by Lehmann and Modest [1994] that no study of which they are aware finds the widest spread of the day at any time other than the market opening. However, their review finds an almost ubiquitous U-shape in intraday spread patterns and the U-shape is absent from the present study.

The widening of the spread in the opening period, and particularly in the first ten minutes, is also in line with the model of Brock and Kleidon [1992], who argue that this is a consequence of buying and selling demand built up during market closure. However, their model also forecasts a comparable widening of the spread towards the market close, as investors seek to close positions rather than hold them overnight. Such a widening is not found in this study.

This larger size of the spread during the $i = 9.00$ interval is, *prima facie*, consistent with Foster and Viswanathan [1990] who argue that intervals with high volatility are likely to contain a high proportion of informed traders and therefore marketmakers are forced to widen the quoted spread in line with the asymmetric information model. However, the analysis of $\Delta P_{i,j}^{trade}$, in Table 6.5, does not support the view that investors in the $i = 9.00$ interval are informed. Indeed, the incidence of significantly positive figures in the $i = 9.00$ row of that table could be taken as an indication that such investors trade at prices which are comparatively ill-informed.

It is worth discussing at this point the nature of informed trading in an index options market. The theoretical classification of investors as liquidity or informed may not be applicable in this case. First, the very nature of options - short-term, wasting assets - makes it less likely that they are used for liquidity trading. Next, informed trading in an index has rather different characteristics from informed trading in individual stocks or stock options. There is a large universe of index-moving information, such as interest rate changes and major economic statistics from around the world, and a plethora of economists and commentators issuing forecasts about the impact of such information. It is therefore arguable that everybody coming to the index options market is informed to some extent, but the heterogeneity of information generates an approximate random walk.

Nevertheless, there still remains scope for (illegal) insider trading by those who have advance knowledge, rather than forecasts, of market-moving information. Even so, marketmakers have some protection against such investors, since they are able to hedge their positions quickly and economically through the futures contract which is traded nearby on the same market. Dawson and Gemmill [1990] outline the mechanics of this on LIFFE. Thus it is argued that informed trading plays only a small part in the determination of the bid-ask spread on these index options and the absence of evidence of informed trading in the present study is consistent with this.

The model of Admati and Pfleiderer [1989] predicts longer runs of bid- or ask-side transactions than can be expected by chance and these are found with a high degree of significance in the present study. However, their model is based on the classification of investors as informed or liquidity and it has been argued above that such a classification may not applicable to the options market. The runs observed in the present study may be attributable to some other phenomenon, such as several investors responding to the same newspaper or stockbroker recommendation. These runs do not appear to be attached to any specific trading interval. Porter [1992] finds a bias towards ask-side transactions in the closing periods of US and Canadian exchanges, towards bid-side transactions on the Canadian exchange during the opening period and towards ask-side transactions on the US exchanges during the opening period, but no biases at all at other times. The present study finds no evidence to reject the null hypothesis of a constant proportion of ask side transactions in each interval.

6.6 CONCLUSION

This study has found partial consistency with, and partial contradiction of, theories relating to the intraday behaviour of the bid-ask spread. The contradictions appear to stem largely from the role in the theories of informed and liquidity traders. It is argued that the standard classification of investors into informed and liquidity traders breaks down in the case of index options, in part because options are inappropriate instruments for liquidity traders and also because the concept of an informed trader has a rather different nature in the case of an index as contrasted with an individual stock. Furthermore, marketmakers in these index options have access to a liquid hedging instrument to hedge the risk of asymmetric information.

The key empirical finding in this study is that there is a significant contraction of both the quoted and effective bid-ask spreads following the first 25 minutes of trading. After this, there is little systematic intraday change in either. This contraction is only partially consistent with theory. For example, it conforms with Brock and Kleidon [1992] who forecast inelastic demand for, and supply of, securities at the beginning and end of the day, with a consequent widening of the spread, but the present study finds a widening only at the beginning of the day. It conforms with Foster and Viswanathan [1990], in that the widest spread is seen during the interval with the highest underlying price variance, but their model is based on the idea of a wider spread being a result of a high incidence of informed trading, whereas in the present study no evidence of informed trading is found during this interval.

The existence of significantly lengthy runs of bid- or ask- side transactions is forecast by Admati and Pfleiderer [1989] and this is observed to a high degree of significance. However, it is argued that a different mechanism from that proposed by Admati and Pfleiderer is responsible for these runs. No evidence is found to associate any of the individual intervals examined with a bias towards bid- or ask-side transactions.

Finally, one of the motivations for this study was the challenge presented by Sheikh and Ronn [1994, p578]. They ask if there is an optimum time during the course of the day for investors to buy and sell options. The conclusion reached here is that there is no such optimum time, but that investors should avoid the opening period of the day, since both the quoted and effective spreads are significantly larger than those at other times with no compensating reward in the form of better prices.

Appendix 6A: SAMPLE HISTORY OF INTRADAY PRICES FOR THE FIRST OBSERVATION IN THE DATABASE

The first observation in the database is of a July 2500 Put option, traded on the ask side of the spread at 08:38:33 on 1 July 1992. Since 08:38:33 falls in the first half hour, i = 9.00. The table below shows the bid, ask trade and index values for observations of that series on the ask side of the spread prevailing at that time and in each subsequent half hour interval, together with the calculated values of Q_i, I_i, Q_j, I_j, $\Delta Q_{i,j}$, $\Delta I_{i,j}$ and $\Delta P_{i,j}$. Empty rows indicate that there was no transaction in that series on the relevant side of the spread in that interval.

i	**Bid**	**Ask**	**Index**	**Trade**	Q_i	I_i			
9.00	18	23	2529.3	22	5.0	1.5			
j	**Bid**	**Ask**	**Index**	**Trade**	Q_j	I_j	$\Delta Q_{i,j}$	$\Delta I_{i,j}$	$\Delta P_{i,j}$
9.30	24	25	2524.1	25	1.0	0.5	4.0	1.0	-3
10.00									
10.30									
11.00	24	27	2515.7	27	3.0	1.5	2.0	0.0	-5
11.30	28	30	2508.0	30	2.0	1.0	3.0	0.5	-8
12.00	32	33	2502.7	33	1.0	0.5	4.0	1.0	-11
12.30	32	33	2503.0	33	1.0	0.5	4.0	1.0	-11
13.00	33	35	2502.1	35	2.0	1.0	3.0	0.5	-13
13.30	33	35	2501.8	35	2.0	1.0	3.0	0.5	-13
14.00									
14.30									
15.00									
15.30	45	47	2490.0	47	2.0	1.0	3.0	0.5	-25
16.00									
16.30									

Appendix 6B: MEAN RETURN AND STANDARD DEVIATION OF RETURNS ON SPOT INDEX AND MEAN NUMBER OF OPTIONS TRANSACTIONS PER 30 MINUTE INTERVAL OVER 96 DAY PERIOD, 1 JULY 1992 TO 12 NOVEMBER 1992 INCLUSIVE

30 mins ending	Mean return	Standard deviation	*t*	Mean number of option trades
9.00	-0.0642%	0.4230%	-1.42	35.9
9.30	-0.0077%	0.2693%	-0.28	30.4
10.00	0.0267%	0.2913%	0.90	25.2
10.30	0.0343%	0.2238%	1.50	21.0
11.00	-0.0397%	0.2334%	-1.67	21.5
11.30	-0.0103%	0.1660%	-0.61	19.4
12.00	-0.0085%	0.1905%	-0.44	15.8
12.30	0.0215%	0.1834%	1.15	12.4
13.00	0.0188%	0.1366%	1.35	10.3
13.30	0.0032%	0.1332%	0.24	8.5
14.00	-0.0042%	0.1430%	-0.28	11.1
14.30	-0.0117%	0.1602%	-0.71	13.2
15.00	-0.0006%	0.2508%	-0.02	16.4
15.30	-0.0348%	0.2769%	-1.23	21.3
16.00	0.0408%	0.1964%	2.03	26.5
16.30	0.0347%	0.1459%	2.33	15.7

Appendix 6C: MEAN VALUES OF PROPORTIONAL QUOTED AND EFFECTIVE SPREADS BY TIME INTERVAL AND TRANSACTIONS PRICE

QUOTED SPREAD

Price Interval ending	0.5-10	10.5-20	20.5-30	30.5-40	40.5-50	50.5-60	60.5-70	70.5-80	80.5-90	90.5-100
9.00	0.4666	0.2513	0.1599	0.1311	0.1047	0.1068	0.0942	0.0779	0.0791	0.0637
9.30	0.4003	0.2020	0.1453	0.1102	0.1011	0.0883	0.0942	0.0773	0.0800	0.0752
10.00	0.4543	0.2254	0.1433	0.1122	0.1044	0.1001	0.0863	0.0739	0.0786	0.0739
10.30	0.4401	0.2075	0.1537	0.1267	0.1058	0.0898	0.0835	0.0756	0.0696	0.0583
11.00	0.4030	0.2178	0.1438	0.1080	0.0968	0.0864	0.0865	0.0773	0.0632	0.0685
11.30	0.4224	0.2135	0.1711	0.1065	0.1069	0.0916	0.0850	0.0861	0.0667	0.0825
12.00	0.3933	0.2064	0.1583	0.1176	0.0977	0.0872	0.0680	0.0749	0.0560	0.0722
12.30	0.3903	0.2222	0.1513	0.1226	0.1274	0.1077	0.0887	0.0821	0.0813	0.0687
13.00	0.4084	0.2246	0.1752	0.1263	0.1154	0.0913	0.0844	0.0836	0.0745	0.0543
13.30	0.4728	0.2198	0.1609	0.1055	0.1057	0.0874	0.0737	0.0778	0.0714	0.0732
14.00	0.4412	0.2132	0.1360	0.1294	0.0898	0.0882	0.0833	0.0671	0.0623	0.0700
14.30	0.3907	0.2138	0.1707	0.1159	0.1176	0.0925	0.0782	0.0669	0.0757	0.0838
15.00	0.3748	0.1977	0.1713	0.1102	0.0950	0.0819	0.0840	0.0800	0.0560	0.0676
15.30	0.3615	0.2097	0.1383	0.1079	0.1028	0.0765	0.0709	0.0664	0.0807	0.0757
16.00	0.4060	0.1916	0.1405	0.1180	0.1058	0.0932	0.0775	0.0677	0.0698	0.0925
16.30	0.3752	0.1879	0.1412	0.0998	0.0951	0.0780	0.0896	0.0727	0.0669	0.0731

EFFECTIVE SPREAD

Price Interval ending	0.5-10	10.5-20	20.5-30	30.5-40	40.5-50	50.5-60	60.5-70	70.5-80	80.5-90	90.5-100
9.00	0.2137	0.0951	0.0600	0.0505	0.0405	0.0412	0.0359	0.0290	0.0326	0.0267
9.30	0.1839	0.0766	0.0532	0.0408	0.0364	0.0336	0.0322	0.0300	0.0298	0.0256
10.00	0.1847	0.0857	0.0529	0.0398	0.0387	0.0370	0.0302	0.0273	0.0284	0.0303
10.30	0.1948	0.0793	0.0567	0.0473	0.0389	0.0311	0.0281	0.0255	0.0258	0.0244
11.00	0.1712	0.0799	0.0532	0.0398	0.0345	0.0306	0.0281	0.0281	0.0228	0.0295
11.30	0.1744	0.0737	0.0642	0.0397	0.0365	0.0352	0.0269	0.0320	0.0244	0.0306
12.00	0.1781	0.0768	0.0585	0.0455	0.0370	0.0321	0.0239	0.0268	0.0209	0.0282
12.30	0.1549	0.0756	0.0535	0.0433	0.0379	0.0383	0.0303	0.0315	0.0317	0.0238
13.00	0.1662	0.0815	0.0573	0.0427	0.0425	0.0301	0.0315	0.0321	0.0307	0.0213
13.30	0.1957	0.0826	0.0531	0.0391	0.0373	0.0328	0.0243	0.0306	0.0249	0.0224
14.00	0.2009	0.0780	0.0519	0.0470	0.0340	0.0353	0.0311	0.0247	0.0230	0.0295
14.30	0.1795	0.0779	0.0641	0.0436	0.0382	0.0355	0.0267	0.0246	0.0293	0.0314
15.00	0.1545	0.0742	0.0561	0.0406	0.0334	0.0315	0.0294	0.0283	0.0214	0.0274
15.30	0.1481	0.0811	0.0515	0.0388	0.0358	0.0293	0.0260	0.0241	0.0301	0.0275
16.00	0.1701	0.0720	0.0532	0.0441	0.0385	0.0359	0.0282	0.0244	0.0234	0.0298
16.30	0.1571	0.0743	0.0543	0.0386	0.0378	0.0288	0.0321	0.0253	0.0256	0.0284

Appendix 6D: MEAN VALUES OF $\Delta Q_{i,j}$ FOR i = 9.00 IN DIFFERENT SUBSAMPLES

Values which are significantly (5%) different from zero are printed in **bold type**.

SUBSAMPLE j	9.30	10.00	10.30	11.00	11.30	12.00	12.30	13.00	13.30	14.00	14.30	15.00	15.30	16.00	16.30
Ask	**0.971**	**0.817**	**0.474**	**0.704**	**1.210**	**0.843**	**0.698**	**0.732**	**0.805**	**0.333**	**0.929**	**0.905**	**0.957**	**0.709**	**0.606**
Bid	**0.716**	**0.883**	**0.346**	**0.603**	**1.370**	**0.446**	**0.947**	**0.897**	**0.722**	**0.768**	**1.024**	**0.718**	**1.007**	**0.792**	**0.794**
Calls	**0.774**	**0.850**	**0.464**	**0.484**	**1.389**	**0.956**	**0.688**	**0.584**	**0.629**	0.340	**0.496**	**0.765**	**0.945**	**0.846**	**0.496**
Puts	**0.710**	**0.757**	**0.452**	**0.704**	**0.508**	0.185	**0.838**	**1.045**	**0.928**	**0.647**	**1.248**	**0.669**	**0.737**	**0.684**	**0.707**
Near dated	**0.871**	**0.756**	**0.491**	**0.598**	**0.919**	**0.551**	**0.964**	**0.791**	**0.878**	**0.793**	**1.222**	**0.813**	**1.090**	**1.013**	**0.915**
Medium dated	**0.538**	**0.721**	0.180	**0.443**	**0.650**	0.258	0.252	0.561	0.381	**-0.569**	-0.193	0.315	0.011	-0.215	-0.491
Deep in the money	0.862	0.192	-0.262	-0.090	0.500	-1.388	**0.876**	1.374	-0.142	0.974	0.834	0.206	1.000	-0.066	1.760
Just in the money	0.296	**0.514**	-0.022	**1.192**	**0.698**	**0.952**	0.512	0.214	**1.064**	0.480	**1.186**	**0.612**	**0.680**	**0.564**	**0.932**
At the money	**0.676**	**0.403**	0.297	0.199	**1.385**	**1.049**	**0.629**	**0.688**	0.584	0.206	**0.750**	**0.850**	**1.110**	**0.853**	0.323
Just out of the money	**0.880**	**1.060**	**0.407**	0.193	**1.087**	0.171	**1.000**	**1.286**	**0.812**	**0.542**	**1.130**	**0.926**	**0.752**	**0.834**	**0.524**
Far out of the money	**0.795**	**1.007**	**1.117**	**1.040**	**0.510**	0.418	**0.757**	**0.593**	**0.747**	**0.628**	**0.816**	**0.495**	**0.648**	**0.739**	0.052

Note: $\Delta Q_{i,j}$ is the change in the quoted spread, so that table entries are the mean changes in the size between the observations in the opening interval (which ends at 09.00) and the intervals ending at the times indicated in the column headings.

Appendix 6E: MEAN VALUES OF $\Delta I_{i,j}$ FOR i = 9.00 IN DIFFERENT SUBSAMPLES

Values which are significantly (5%) different from zero are printed in **bold type**.

j	9.30	10.00	10.30	11.00	11.30	12.00	12.30	13.00	13.30	14.00	14.30	15.00	15.30	16.00	16.30
SUBSAMPLE															
Ask	**0.562**	**0.519**	**0.389**	**0.409**	**0.580**	**0.430**	**0.347**	**0.645**	**0.410**	**0.367**	**0.361**	**0.361**	**0.432**	**0.378**	**0.492**
Bid	**0.448**	**0.483**	**0.384**	**0.276**	**0.657**	0.199	**0.414**	**0.444**	**0.438**	**0.579**	**0.404**	**0.164**	**0.440**	**0.328**	**0.476**
Calls	**0.484**	**0.522**	**0.438**	**0.489**	**0.616**	**0.517**	**0.441**	**0.345**	**0.573**	**0.574**	**0.305**	**0.205**	**0.409**	**0.501**	**0.442**
Puts	**0.272**	**0.253**	**0.287**	**0.212**	**0.244**	**-0.027**	**0.331**	**0.536**	**0.304**	**0.158**	**0.413**	**0.331**	**0.361**	**0.158**	**0.328**
Near dated	**0.427**	**0.379**	**0.364**	**0.367**	**0.453**	**0.225**	**0.496**	**0.411**	**0.467**	**0.429**	**0.454**	**0.292**	**0.473**	**0.424**	**0.477**
Medium dated	**0.192**	**0.225**	**0.218**	0.138	**0.180**	0.176	0.084	**0.476**	0.237	-0.074	-0.057	0.160	0.097	-0.109	0.079
Deep in the money	**1.447**	**1.022**	0.681	0.136	1.212	-0.061	0.338	0.613	-0.214	**2.231**	0.333	0.410	**0.670**	-0.112	**2.163**
Just in the money	**0.243**	0.180	0.191	**0.400**	**0.431**	**0.447**	0.322	0.229	**0.451**	0.225	**0.489**	**0.225**	**0.345**	**0.244**	**0.451**
At the money	**0.315**	**0.280**	**0.261**	0.087	**0.623**	**0.397**	0.224	**0.477**	**0.580**	-0.005	**0.370**	0.214	**0.610**	**0.514**	0 103
Just out of the money	**0.200**	**0.324**	0.117	**0.246**	**0.239**	-0.138	**0.320**	**0.501**	**0.268**	0.090	**0.327**	**0.221**	**0.217**	**0.230**	**0.180**
Far out of the money	**0.313**	**0.369**	**0.576**	**0.469**	0.191	**0.274**	**0.572**	**0.327**	**0.341**	**0.427**	**0.316**	**0.345**	**0.278**	**0.377**	**0.219**

Note: $\Delta I_{i,j}$ is the change in the effective spread, so that table entries are the mean changes in the size between the observations in the opening interval (which ends at 09.00) and the intervals ending at the times indicated in the column headings.

Appendix 6F: MEAN VALUES OF $\Delta P_{i,j}^{trade}$ FOR THE FIRST AND SECOND HALVES OF THE DATABASE

The times indicated in the row and column headings mark the end of the thirty minute intervals represented by i and j respectively. Mean values of $\Delta P_{i,j}$ which are significantly (5%) different from zero are indicated in **bold type** The top part of the table shows results from the first half of the database and the bottom part shows results from the second half. The mean sample size for the first half is 267 observations per (i, j) pairing with a maximum of 760 for the pair ($i = 9.00, j = 9.30$) and a minimum of 63 for the pair ($i = 12.30, j = 14.00$). For the second half, the mean sample size is 261 observations per (i, j) pairing with a maximum of 743 the pair ($i = 8.50, j = 9.30$) and a minimum of 93 for the pair ($i = 13.30, j = 14.00$).The values are expressed in index points, which can be multiplied by £10 to give a monetary value per contract.

FIRST HALF OF SAMPLE (1 July - 7 September)

j / i	9.30	10.00	10.30	11.00	11.30	12.00	12.30	13.00	13.30	14.00	14.30	15.00	15.30	16.00	16.30
9.00	-0.274	-0.245	-0.478	0.145	0.356	0.292	0.990	-0.419	**-2.422**	0.797	-0.217	0.397	**1.168**	0.353	-0.176
9.30		-0.080	-0.401	-0.371	-0.031	-0.710	0.089	**-1.609**	-1.041	-0.395	-0.364	0.554	**1.365**	0.098	0.153
10.00			-0.393	0.103	**0.869**	-0.484	0.853	0.146	-0.236	-0.160	1.210	**1.211**	**2.046**	**1.763**	**2.296**
10.30				-0.169	**-0.695**	-0.363	-0.475	-0.375	-1.563	0.285	0.414	1.079	0.986	0.595	-0.466
11.00					0.025	**-0.639**	0.322	0.241	-1.146	-0.061	0.127	**1.396**	0.405	0.424	0.214
11.30						0.093	0.491	**-1.042**	**-1.451**	-0.197	0.195	-0.113	-0.201	-0.420	-0.300
12.00							-0.097	-0.862	-0.863	-0.257	-0.072	0.077	0.662	-0.422	0.710
12.30								**-2.061**	**-2.412**	-1.409	-0.521	-0.855	-0.382	-0.325	-0.358
13.00									-0.406	-0.606	**-1.199**	-0.390	-0.112	-1.028	1.526
13.30										0.225	**-1.074**	-0.041	-0.393	**-1.740**	0.625
14.00											-0.138	-0.140	-0.261	**-1.899**	1.090
14.30												0.160	0.231	**-1.711**	-0.421
15.00													0.005	-0.315	0.441
15.30														**-0.447**	0.532
16.00															-0.243

Appendix 6F (cont.): **MEAN VALUES OF $\Delta P_{i,j}^{trade}$ FOR THE FIRST AND SECOND HALVES OF THE DATABASE**

SECOND HALF OF SAMPLE (8 September - 12 November)

i \ *j*	9.30	10.00	10.30	11.00	11.30	12.00	12.30	13.00	13.30	14.00	14.30	15.00	15.30	16.00	16.30
9.00	-0.553	-0.386	**1.872**	0.896	**2.814**	**2.223**	**2.386**	**2.992**	**1.960**	**1.992**	1.560	0.090	-0.088	**2.659**	**2.706**
9.30		-0.330	0.663	0.283	**1.356**	0.041	-0.167	**1.945**	0.415	**2.174**	0.858	0.558	0.336	**2.282**	1.421
10.00			0.677	0.412	**1.193**	-0.159	**1.303**	1.108	-0.995	**2.590**	0.946	0.207	-1.681	1.113	0.405
10.30				-0.411	0.730	0.518	-0.687	-1.109	-0.208	1.266	**2.504**	0.658	-0.225	**2.224**	-1.857
11.00					0.042	0.475	-0.786	0.811	-1.214	0.494	0.585	-0.073	0.577	0.816	-0.090
11.30						-0.643	**-1.429**	-1.418	-1.403	**1.358**	-0.086	0.141	**-2.357**	0.248	-1.327
12.00							-0.453	**-1.045**	**-2.321**	0.133	-0.884	-1.092	**-3.477**	-1.708	**-3.183**
12.30								0.198	-0.279	-0.320	-0.847	0.307	1.481	0.997	0.708
13.00									-0.869	-0.455	**-1.456**	-0.171	-0.572	-1.648	1.672
13.30										-0.141	-1.053	-0.816	0.187	0.112	-1.247
14.00											**-1.007**	-0.709	0.492	-0.348	-1.362
14.30												-0.571	-0.341	0.537	1.617
15.00													-0.309	-0.012	0.962
15.30														-0.739	0.306
16.00															**1.150**

Appendix 6G: RESULTS OF χ^2 TEST OF EQUAL INCIDENCE OF ASK-SIDE TRANSACTIONS DURING EACH INTERVAL

The test is of the null hypothesis that the incidence of ask-side transactions is equal across all intervals. The test is undertaken for the full sample and for the put and call subsamples. Since there are 15 degrees of freedom, the 5% threshold of significance is $\chi^2 = 24.9958$. This threshold is not reached in any of the three tests.

	FULL SAMPLE				PUTS				CALLS			
Interval Ending	**n**	**Observed (O)**	**Expected (E)**	**$\frac{(O-E)^2}{E}$**	**n**	**Observed (O)**	**Expected (E)**	**$\frac{(O-E)^2}{E}$**	**n**	**Observed (O)**	**Expected (E)**	**$\frac{(O-E)^2}{E}$**
9.00	3,181	1,643	1,604	0.9568	1,708	912	870	2.0235	1,473	731	734	0.0112
9.30	2,691	1,346	1,357	0.0855	1,384	701	705	0.0227	1,307	645	651	0.0584
10.00	2,257	1,125	1,138	0.1475	1,232	611	628	0.4375	1,025	514	511	0.0217
10.30	1,919	934	968	1.1626	966	462	492	1.8379	953	472	475	0.0165
11.00	1,961	993	989	0.0186	1,068	533	544	0.2237	893	460	445	0.5120
11.30	1,808	881	912	1.0255	1,015	514	517	0.0178	793	367	395	1.9965
12.00	1,498	789	755	1.5059	766	411	390	1.1094	732	378	365	0.4855
12.30	1,128	532	569	2.3715	617	279	314	3.9635	511	253	255	0.0099
13.00	930	444	469	1.3219	473	224	241	1.1913	457	220	228	0.2594
13.30	824	418	415	0.0156	443	235	226	0.3865	381	183	190	0.2450
14.00	1,035	544	522	0.9414	598	327	305	1.6448	437	217	218	0.0024
14.30	1,216	620	613	0.0778	677	356	345	0.3600	539	264	269	0.0767
15.00	1,462	757	737	0.5359	805	420	410	0.2409	657	337	327	0.2858
15.30	1,932	991	974	0.2934	1,063	546	541	0.0377	869	445	433	0.3354
16.00	2,412	1,195	1,216	0.3662	1,214	609	618	0.1429	1,198	586	597	0.1977
16.30	1,436	749	724	0.8622	771	399	393	0.0997	665	350	331	1.0540
TOTAL	27,690	13,961	13,961	**11.6883**	14,800	7,539	7,539	**13.7399**	12,890	6,422	6,422	**5.5681**

Chapter 7

CONCLUSION

7.1 PRESCRIBED INVESTOR BEHAVIOUR

In Section 1.1 of this thesis, it was stated that the common theme in the studies was how an investor could circumvent the problems, or exploit the opportunities, presented by the institutional characteristics of the market. A review of the key findings of the research follows:

i. The wildcard option

The wildcard option has received widespread attention in the literature recently and it appears to be of considerable significance for OEX options. Using strong assumptions to ensure the maximum possible inclusion, simple boundary conditions are derived which embrace all circumstances in which the wildcard option might be of value and it is found that these are met in only a very small percentage of options series.

There are inevitably time delays involved in the communications process for option exercise. An investor has to call a broker and the broker has to communicate the exercise decision to the London Options Clearing House before 16.31. The delay is likely to be longest for private investors, who will thus be unable to incorporate all of the information flow during the wildcard interval into their exercise decisions. The analysis in Chapter 2 of this thesis indicates that this is unlikely to be a major handicap. Whilst Chapter 3 stressed the need for investors to delay the exercise decision until the last possible moment, the underlying market is so quiet during the wildcard interval that the final 21 minutes are unlikely to be crucial.

ii. Early exercise

Five hypotheses of rational investor behaviour are derived in Section 3.4. At the heart of these is the observation that the transactions cost structure makes it more economical for both holders and writers of rationally exercised, delivery-settled options to close their positions by a market transaction rather than through exercise, unless they wish to use exercise to make a permanent or semi-permanent change in their inventory of the underlying asset. The simultaneous supply of both buy-side and sell-side liquidity at the time of rational exercise should minimise the need for marketmaker participation in such closing transactions and hence reduce the bid-ask spread. A reduction is seen for call options, but not for puts, and it is conjectured that marketmakers take a significant proportion of the open interest on the short side of put option transactions and thus have an interest in keeping the spread as wide as possible.

Cash-settled options have different characteristics. Exercise and market sale are equivalent, in that they change the risk in the investor's portfolio in exactly the same way, and the cash settlement of both takes place at 10.00 the following working day. Thus an exercise strategy for cash-settled options is much simpler: the investor who wishes to close a position at the end of the day should instruct a broker to await the determination of the settlement price at 16.10 and then to sell in the closing rotation or to exercise, according to which offers the greater value.

The only significant inefficiency observed is that a number of option holders exercise prematurely within an account. This exposes them to a small amount of information risk, but also causes their counterparties to incur transactions costs which they might otherwise have expected to avoid by buying back their short position later in the account. The abolition of the account system should reduce the incidence of this, since put option exercise may now be rational on any day and the option holder who exercises a call option earlier than the final cum-dividend trading day, or at expiry, will suffer a cashflow disadvantage as well as bearing information risk.

iii. Comparative pricing of European and American options

The database shows a marked investor preference for American style index options. This is irrational in the case of most call options, since the pattern of the dividend stream generally renders the early exercise privilege worthless, according to the boundary condition derived in Chapter 4. Boundary condition tests of both put and call options show a persistent, but unsystematic, mispricing between the two. In some cases, the American options are overvalued in comparison with the Europeans, whilst in other cases, the reverse is observed.

Simulation of an *ex ante* trading rule fails to show arbitrage profits, but the simulation is hindered by the lack of bid-ask quotes for the European options. Nevertheless, an alternative order placement strategy is indicated. Using this strategy, investors would instruct their brokers to call for prices on two option series - an American one and a nearby European one - and to trade in that style which appears to be more finely priced. The exercise prices of the two are offset by 25 index points, less than 1% of the index level prevailing during the tests, so investor preference for a given degree of moneyness can be accommodated with either style of option. Adoption of such a strategy should lead to an increase in the frequency of quotes and trades for the European options and an elimination of the observed incidence of mispricing, *iv. Competing with marketmakers through limit orders*

Order placement strategy forms the central core of chapter 5 of the thesis. Phillips and Smith [1980] discuss the impact of the bid-ask spread on investment performance in option markets. A limit order facility, enabling retail investors to capture some or all of this spread for themselves, exists on LIFFE but appears to be little used. Investors who do use it face two types of information risk and appear, *prima facie*, to be unrewarded for so doing. Nevertheless, the risks can be limited by the empirical observation that, where execution of limit orders does take place, it generally occurs within a short time of order placement. Thus it is possible for investors to limit the amount of time they are exposed to the twin information risks to a period which is found to be demonstrably rewarding in terms of bid-ask spread capture. The optimal interval appears to be of about 120 minutes duration.

The strategy proposed is tested *ex ante* on the quote and trade database. Using the criteria of success defined in Chapter 5, the strategy is found to offer an improvement over the twin alternatives of:

i. leaving the option open for the remainder of the trading day, or

ii. trading at the prevailing market prices rather than submitting a limit order.

The improvement over *i.* is significant (1%) for stock options, but not for index options. The improvement over *ii.* is significant (1%) for both stock and index options. However, the analysis has not been able to determine the optimum level of target spread capture and so still leaves a large area of judgement open to the investor.

v. Intraday behaviour of the bid-ask spread

There are (sometimes conflicting) theoretical grounds to associate certain times of the day with favourable or unfavourable trading environments. Sheikh and Ronn [1994] suggest empirical research to determine the optimum time of the day to trade options. A series of tests of different aspects of the intraday behaviour of quoted and effective spreads fails to answer this point definitively, but suggests avoiding the opening 25 minutes, when the indirect transactions costs are highest with no compensation in the form of informative trading prices. LIFFE demonstrates the apparently ubiquitous phenomenon of spreads being widest at the market opening, but little systematic behaviour in the spread is seen thereafter. No particular time of day is associated with significantly favourable or unfavourable transactions prices, so the investor hoping for a free ride with informed traders or protection against adverse selection is unaided by this study.

7.2 CONTRIBUTIONS TO THE LITERATURE

In addition to help in improving investor performance, it is hoped that this thesis has made a number of contributions to the academic literature on options markets:

i. The wildcard option

The wildcard option has received considerable attention recently. As Diz and Finucane [1994] point out, there is disagreement in the literature over its significance. French and Maberly [1992] describe the wildcard option as a complicated one to price, but Fleming and Whaley [1994] provide a relatively straightforward modification to the binomial model to incorporate the wildcard feature. Chapter 3 develops three boundary conditions each for call (**2.1**, **2.3** and **2.5**) and put (**2.2**, **2.4** and **2.6**) options to be affected by the wildcard option. Strong assumptions are made in deriving these conditions, to ensure maximum possible inclusion, but even so it is found that on LIFFE, very few options series comply with these conditions.

This finding is markedly different from studies of OEX options and the difference is attributed to the near-moribund nature of the London cash market during the wildcard interval. Application of the Fleming and Whaley model to the London market produces a valuation of the wildcard option consistent with the results of the boundary condition tests.

ii. Early exercise

There appears to be only one previous study of early exercise practice (Diz and Finucane [1994]), and that is concerned solely with cash-settled options. As Chapter 3 details, the frictions involved in the exercise of delivery-settled options impose a markedly different set of conditions on an option holder. These conditions generate a set of five testable hypotheses, whereas the cash-settled options generate only a single testable hypothesis. In general, investor behaviour conforms closely with these hypotheses, although some significant differences are observed between the cases of call and put options.

These differences are attributed to two clientele effects: the generally more rational behaviour on the part of put option holders indicates a more experienced set of investors, whereas the absence of a significant narrowing of the bid-ask spread as put options become rationally exercised implies that a significant supply of put options comes from marketmakers, who generally face fewer restrictions than other investors in taking short positions in the underlying stocks. This is in line with Figlewski and Webb [1990].

iii. Comparative pricing of American and European options

LIFFE appears to be unique in trading both styles of contract on the same underlying index and Chapter 4 is the first comparative analysis of these prices.

Considerable attention has been given to pricing the early exercise right. For call options, a model proposed by Roll [1977], simplified by Geske [1979] and modified by Whaley [1981] has been given considerable empirical attention. The problems imposed by American put options have proved to be more intractable. As shown in Chapter 4, the Blomeyer and Johnson [1989] test of the Geske-Johnson [1984] model shows an underestimate of the market price. These models require stronger assumptions than are used in boundary condition tests.

Merton [1973] proves a number of boundary conditions applying to option pricing. Two of these are modified in Chapter 4 to produce simple and model-independent conditions for the pricing of the early exercise right for calls and puts. **(4.2)** determines whether or not a call option can be priced as a European option, and thus avoid the complications of the early exercise right. It transpires that most American index call options will not be rationally exercised. **(4.4)** gives a convexity condition which applies to butterfly spreads consisting of European put options held long and American put options sold short.

iv. Competing with marketmakers through limit orders

Limit orders are of particular interest in option markets, for two reasons. First, the proportionate bid-ask spread tends to be larger in options markets than in the markets for other financial assets. Second, the volatile nature of an option price makes it more important for investors who cannot monitor the market continuously to have access to a mechanism which can capture attractive prices. The dual role which limit orders play for investors, namely monitoring the market for attractive prices and providing competition for marketmakers, has not been recognised previously. Other commentators have discussed one or other role, but not both.

The twin information risks faced by limit order investors are discussed and a distinction is drawn between these risks and those faced by the marketmakers with whom limit order investors are assumed to compete. Copeland and Galai [1983] describe marketmaking activity in terms of a short position in an option strangle. However, a marketmaker quote on LIFFE is binding only for the instant at which it is issued, and so, in the terms of Copeland and Galai, is an option strangle with an instantaneous maturity. In contrast, a limit order is good for the day, and, whilst in theory it may be withdrawn at any time, in practice the communications process and the fact that retail investors cannot be expected to monitor the information flow continuously, mean that they are exposed to the risk of exercise being triggered by the arrival of adverse information.

The CMSW [1981] model is difficult to apply empirically, because it requires assumptions about investor utility functions and the probability of execution at different limit order prices. Chapter 5 presents a set of criteria to determine the success or failure of a limit order, whether executed or not and analyses observed practice according to these criteria. It transpires that the average limit order fails: those which are executed qualify as successes, although the extent of their success is inhibited by the adverse information risk described. The extent of this success is outweighed by the extent of failure of those orders which are not executed. The failure of these is reinforced by the risks of beneficial information, which moves the market price away from the limit price and thus leaves investors unable to gain from the price improvement.

v. *Intraday behaviour of the bid-ask spread*

A variety of theoretical models exist for the intraday behaviour of securities prices. Chapter 6 tests the database for conformity with these theories. The results show partial conformity and partial contradiction. In the discussion, Section 6.5, it is suggested that the contradictions arise from the distinction in the theory between informed and liquidity traders. The financial instruments analysed in the chapter are index options, and it is argued that the theoretical models are less valid for such a market for three reasons:

i. as short-term, wasting, assets, options are less likely to be used for liquidity trading,

ii. informed trading in an index has rather different characteristics from informed trading in individual stocks, and

iii. marketmakers have access to a liquid instrument to hedge the risk of asymmetric information.

The key empirical finding of Chapter 6 is that the bid-ask spread is at its widest during the first 25 minutes of trading. This is in accordance with Mayhew [1993] who also studies an options market and also with the comment by Lehmann and Modest [1994] that no study of which they are aware has found the spread to be widest at any time other than market opening. This applies across all financial instruments in all countries. However, their review also finds an almost ubiquitous U-shape for the bid-ask spread during the day and that shape is not observed on LIFFE.

7.3 FURTHER RESEARCH

To complete this thesis, a number of areas for further research are suggested:

i. The introduction of the Autoquote system, described in footnote 2 of Chapter 1, offers considerable research potential. A model is used to produce continuous real-time quotes and comparison of the prices generated by this model with observed transactions prices provides the opportunity for an extensive test of the underlying model.

ii. The wildcard option will undoubtedly continue to attract theoretical interest and further empirical study in US markets. However, until the volatility of the FT-SE 100 index increases during the wildcard interval, it is argued that little further empirical research is necessary for the UK market.

iii. Appendix 3A outlines the changes involved in the abandonment of the account system on the London Stock Exchange. It is argued that one of the effects of this will be to make exercise practice more efficient, particularly with respect to the timing of exercise, since premature exercise will bring a cashflow penalty as well as exposing the option holder to information risk.

iv. LIFFE [1994] argues that the abandonment of the account system will lead to greater interest in individual equity options. This forecast awaits testing.

v. It was conjectured at the end of Chapter 4 that a change in order placement strategy would both eliminate the incidence of mispricing between the American and European options and also increase the volumes traded in the European options. This conjecture awaits testing.

vi. Further research remains to be undertaken on the optimal limit order strategy. In particular, the question of how much of the bid-ask spread an investor should target remains unanswered. The analysis in Chapter 5 was hindered by the fact that so many of the limit orders in the database (54.4% for stock options and 72.5% for index options) target 100% of the quoted spread, leaving a relatively small number of observations of smaller targets to be analysed. A larger database and/or a different methodology, perhaps involving assumptions about order arrival rates, may shed more light on this important question.

vii. The role and effectiveness of monitoring limit orders merits further research. As Berkman [1991] points out, such orders give the marketmakers a free insurance policy. The rewards for providing this welfare deserve analysis.

viii. Finally, the question posed by Sheikh and Ronn [1994] about the best time of day for an investor to buy or sell options remains only partly answered. It appears that investors should avoid the early part of the day, in which the spreads are widest and there appears to be no compensating gain in the form of more informative prices. Apart from this, the thesis has found no optimal trading time.

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