A Study of Arbitrage Efficiency Between the FTSE-100 Index Futures and Options Contracts

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Despite the importance of the London markets and the significance of the relationship for market makers, little published research is available on arbitrage between the FTSE-100 Index futures and the FTSE-100 European index options contracts. This study uses the put–call–futures parity condition to throw light on the relationship between options and futures written against the FTSE Index. The arbitrage methodology adopted in this study avoids many of the problems that have affected prior research on the relationship between options or futures prices and the underlying index. The problems that arise from nonsynchroneity between options and futures prices are reduced by the matching of options and futures prices within narrow time intervals with time-stamped transaction data. This study allows for realistic trading and market-impact costs. The feasibility of strategies such as execute-and-hold and early unwinding is

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examined with both ex-post and ex-ante simulation tests that take into consideration possible execution time lags for the arbitrage trade. This study reveals that the occurrence of matched put–call–futures trios exhibits a U-shaped intraday pattern with a concentration at both open and close, although the magnitude of observed mispricings has no discernible intraday pattern. Ex-post arbitrage profits for traders facing transaction costs are concentrated in at-the-money options. As in other major markets, despite important microstructure differences, opportunities are generally rapidly extinguished in less than 3 min. The results suggest that arbitrage opportunities for traders facing transaction costs are small in number and confirm the efficiency of trading on the London International Financial Futures and Options Exchange.
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INTRODUCTION

This study uses the put–call–futures parity relationship to examine the arbitrage possibilities between FTSE-100 Index options and futures traded on the London International Financial Futures and Options Exchange (LIFFE). The London markets are among the largest in the world. LIFFE ranked as the largest European futures and options exchange by value, and the London Stock Exchange ranked as the third largest national stock market.[1] Yadav and Pope (1994) examined arbitrage possibilities between futures and cash. There are, however, as yet no published studies that examine LIFFE futures–options arbitrage despite the importance of the strategy.[2] As Lee and Nayar (1993, p. 890) commented, "market makers in SPX options are continually hedging their positions with the companion S&P 500 futures contracts." By directly pricing the options contracts with the futures contracts (and vice versa), this study avoids the problems encountered in arbitraging between options or futures contracts and the underlying cash index. These problems include both high transaction and market-impact costs and the inclusion of stale prices in the index arising from the nontrading of constituent stocks.

The application of the put–call–futures parity relationship for FTSE-100 contracts is possible because FTSE options and futures contracts have overlapping expiration cycles and identical underlying assets and settle, in both cases, with the exchange delivery settlement price

[1]The notional value (US$m) is taken from the International Federation of Stock Exchanges for 1998.

[2]Ap Gwilym and Sutcliffe (1999) provided a comprehensive survey of arbitrage studies of major markets.

(EDSP).[3] In addition, the existence and use in this study of European-style FTSE-100 Index options (ESX) eliminate the possibility of early exercise in the option leg of the arbitrage portfolio.

This study uses time-stamped bid–ask quotes and traded prices for both contracts. The data permit the matching of traded prices within narrow time intervals of 1 min. This reduces the nonsynchronous price problem. We allow for trading and market-impact costs, with market-impact costs determined from bid–ask quotes. The feasibility of execute-and-hold and early-unwinding strategies is examined with ex-post and ex-ante simulation tests. This study also examines whether there is any significant intraday variation in the pattern of the distribution of mispricings. The ex-ante simulations allow for possible execution time lags in establishing each leg of the arbitrage trade. The relationship between arbitrage profit and spread costs, time to maturity, types of strategies adopted, and market volatility (as implied by the futures and options prices) is also examined.

This study reveals that the occurrence of matched put–call–futures trios exhibits a U-shaped intraday pattern, with concentrations at both open and close. The magnitude of the observed mispricings, however, has no discernible intraday pattern.[4] This study finds ex-post arbitrage profits for traders facing transaction costs are limited and generally are rapidly extinguished in less than 3 min. Profits are larger the greater the spread, volatility, and time to maturity are, but the average ex-post profit is very close to the ex-ante profit for lags of less than 3 min. Long-futures trades are marginally more profitable than short-futures strategies. Early unwinding may also be profitable, but for traders facing even low levels of transaction costs, the number of opportunities is small.

The results provide important confirmation for the results derived by Lee and Nayar (1993) and Fung and Chan (1994) for the Standard and Poor's (S&P) 500 and by Fung and Fung (1997a) for the Hong Kong Hang Seng Index. All three markets exhibit market efficiency and are consistent with the conclusions of Fleming, Ostdiek, and Whaley (1996), who found that traders price options off the futures. This result holds despite important differences in the microstructure, including the absence of any price limits on the FTSE futures in contrast to the

[3]The FTSE-100 futures and ESX options contracts share an identical underlying asset delivery price: the EDSP. Since September 1991, the EDSP has been calculated by values of the index being measured on a minute by minute basis between 10.10 a.m. and 10.30 a.m. on the last trading day. The average value is calculated from the middle 15 prices after the three highest and three lowest values are discarded. The result is rounded to the nearest 0.5 index point.

[4]Thanks are due to one of the referees for encouraging us to explore the intraday characteristics of the data.

S&P 500 futures, differences in settlement price calculations between the markets, and, perhaps most importantly, differences in the number of traders in each market.[5]

This article is organized as follows. The second section examines the relationships between options and futures contracts, the third section defines the trigger conditions and profitability of the arbitrage trades, the fourth section describes the data and methodology, and the fifth section discusses the empirical findings.

PRICING EFFICIENCY OF OPTIONS AND FUTURES CONTRACTS

A number of authors have examined the pricing efficiency of index options and index futures contracts with varying degrees of concern for the numerous frictions that impede the arbitrage process, resulting from the cost and difficulty of trading the underlying index basket. The arbitrage process assumes, at its simplest, a frictionless market in which traders and hedgers initiate transactions whenever options and futures prices deviate from the fair price relative to the cash index. Impediments to this ideal arbitrage process include, in addition to regulatory restrictions and barriers, both transaction costs arising from necessary trading strategies and risks arising from the arbitrage process. The impact of regulatory restrictions is generally difficult to quantify, but restrictions include both exchange-imposed regulations relating to such concerns as margin size and short selling and the effects that arise from differential tax treatment of the trading of futures, options, and underlying stocks.

These factors create significant arbitrage-free bands around the futures and options contracts relative to the underlying cash position. A considerable number of articles[6] have documented significant variation

[5]Since 1998, Liffe has gradually migrated its contracts from open outcry to electronic trading, a process that is now complete. It would be interesting to study the impact of this change on the parity–price relationship. We would expect the net effect to be a tradeoff between narrower spreads and greater market efficiency due to a higher level of execution efficiency and transparency in the trading process. If electronic trading narrows the effective bid–ask spread in the options and futures markets, it may increase the frequency of the arbitrage opportunity, but the faster execution speed and greater transparency will offset some or all of this impact. The robustness of the results across different market structures suggests that it is unlikely that our overall results would be seriously changed in an electronic trading environment. The close relationship between index options and futures prices found in this study also suggests that the impact on the parity–price relationship would be marginal.

[6]For example, for the United States, see Modest and Sundaresan (1983), Figlewski (1984), Mackinlay and Ramaswamy (1988), Chung (1991), and Bhatt and Cakici (1990). For the United Kingdom, see Yadav and Pope (1990). For Japan, see Brenner, Subrahmanyam, and Uno (1989, 1990), Lim (1992), and Chung, Kang, and Rhee (1996). See Fung and Draper (1999) for the Hong Kong market, Puttonen (1993) for the Finnish market, and Buhler and Kempf (1995) for the German market. See ap Gwilym and Sutcliffe (1999) for a comprehensive survey.

in the futures and option prices relative to the index (although the deviations are not always sufficient to guarantee riskless arbitrage and significant profits). Yadav and Pope (1994), for example, in a definitive study for the United Kingdom examining futures against the cash index, reported that the absolute magnitude of mispricing often exceeds the estimated trading costs and cannot be explained by dividend uncertainty, marking-to-market cash flows, or possible delays in trade execution. For option contracts written against futures, the problems caused by such factors are substantially reduced because the options can be priced (arbitraged) directly against the underlying futures contract (Sternberg, 1994). Indeed, for markets where index futures and index options are traded parallel to one another, the options can be priced directly from the futures contracts.[7] This allows a direct evaluation of the pricing efficiency of the options by comparing the options prices with those of the futures that mature at the same time.

Market makers in options commonly use futures contracts to hedge their positions. Fleming et al. (1996) found evidence that dealers price the S&P 100 Index options relative to the prevailing S&P 500 futures price. It is cheaper and more convenient to hedge the options with the futures than with the stock basket. Arbitrage-free bounds around futures–options trading should be smaller than those found by Yadav and Pope in investigating futures–cash trading.

Recognizing that buying a call and writing a put at the same exercise price will lock in a sure cash flow equal to the difference between the concurrent futures price and the exercise price, Tucker (1991) established the put–call–futures parity relation:

$$C_0(X) - P_0(X) = (F_0 - X)(1 + r)^{t_0 - T} \tag{1}$$

where $C_0(X)$ and $P_0(X)$ denote the prices of European call and put options, respectively, on day t_0 with the same exercise price (X) and expiration day (T). F_0 represents a futures contract with the same time to maturity as the options. The prices for all three contracts are synchronous for the particular portfolio and are all written on the same underlying asset. r is the riskless rate of interest for the holding period between t_0 and T.[8] When the futures price equals the common exercise price of the options (i.e., $F_0 = X$), buying the call and writing the put exactly mimic the futures payoff. Call and put prices will also be equal. Deviations from Equation 1 provide opportunities for profitable arbitrage. If the put is

[7]For European options and futures that share the same underlying asset and common expiration day, the option can be priced as if it is an option on the futures contract (Black, 1976).
[8]t_0 and T are both in fractions of a year.

undervalued according to the parity relationship and the call is overvalued, we can mimic the expensive call by buying the put and going long in the futures. This allows us to arbitrage the portfolio with the overpriced call. If, however, the call is cheap and the put is overvalued, we buy the call and short the futures to mimic the put. This allows us to arbitrage the overpriced put with the call option and futures contract.

The parity condition (Equation 1) is widely used in practice. Lee and Nayar (1993) and Fung and Chan (1994) applied the condition to study the S&P 500 options and futures contracts traded on the Chicago Board Options Exchange and Chicago Mercantile Exchange, respectively. Fung, Cheng, and Chan (1997) and Fung and Fung (1997a) further adapted the condition to study the joint pricing efficiency of the Hang Seng Index options and futures contracts traded on the Hong Kong Futures Exchange. Lioulíou (1995) examined the relationship between the FTSE-100 futures European-style (ESX) contracts with daily closing prices for the period February 1992 to February 1995.

The use of the parity condition permits a direct investigation of arbitrage efficiency between options and futures contracts and avoids a number of the major problems associated with studying the relationships between the contracts and their underlying index. Specifically, because the options are priced from the futures, or vice versa, the difficulties caused by nonsynchroneity of trading and stale prices that affect arbitrage with a broad-based index are greatly reduced. The parity condition is also immune to uncertainty over dividend payouts (Fung & Chan, 1994), a factor that is particularly important to most contracts that do not settle against a full performance index. Furthermore, for options and futures that settle against an average of the index, arbitrageurs run the risk of mismatching the settlement value, the average of the index, and the actual closeout value of the equity position (Fung et al., 1997; Yadav & Pope, 1994). To reduce the magnitude of the potential error, arbitrageurs may choose to proportionally close out their equity position over the index at intervals, although this will produce extra market-impact costs (Fung & Fung, 1997b). For the FTSE-100 contract, an additional risk is present because the maximum and minimum values are determined only after all relevant index values have been taken. Fortunately, if both the options and the futures share identical settlement methods (see Fung et al., 1997; Fung & Fung, 1997a), using the parity relationship avoids such difficulties. In addition, because there are no restrictions preventing the taking of short positions in futures and writing options, in contrast to those that exist with regard to equities, the put–call–futures parity should hold more accurately than for arbitrage with the index.

ARBITRAGE TRIGGERS FOR THE EXECUTE-AND-HOLD AND EARLY-UNWINDING STRATEGIES

If we ignore the costs attributable to identifying arbitrage possibilities, arbitrage will only take place when the deviation between the futures price and its parity value is sufficient to cover the marginal cost of the position. The direct costs of arbitrage include the opportunity cost of funds for the margin deposits, the trading cost, and the market-impact cost. Market-impact cost consists of the bid–ask price spread (hereafter, the spread cost) and possible pressure exerted on market prices due to (large) arbitrage-related trading (Kawaller, 1987).

Cash margin account deposits with LIFFE are credited with market interest, whereas interest-bearing securities may be used as collateral. This lowers the opportunity cost of funds for arbitrage trades, and for this reason, this study assumes a zero cost of funds for all participants.[9] However, trading and spread costs will affect the profitability of strategies.

Arbitrage Trigger for the Execute-and-Hold Strategy

For the execute-and-hold strategy, given the spread cost (ψ_0) and round-trip trading cost (τ_0), the upper no-arbitrage bound for the futures price (F_0^+) can be written as follows:

$$F_0^+ = F_0^* + \psi_0 + \tau_0 \tag{2}$$

where F_0^* is the fair price of the futures given in Equation 1. A short-futures arbitrage strategy is warranted if the actual futures price (F_0) is above F_0^+, and the magnitude of the profit from the strategy e^+, is equal to

$$e^+ = F_0 - F_0^+ \tag{3}$$

where $F_0 > F_0^+$. Similarly, the lower no-arbitrage bound (F_0^-) for the futures price can be written as

$$F_0^- = F_0^* - (\psi_0 + \tau_0) \tag{4}$$

A long-futures arbitrage strategy should be undertaken if the future price drops below F_0^-. The magnitude of the profit from the strategy e^- can be written as

$$e^- = F_0^- - F_0 \tag{5}$$

[9]For a discussion of how margin costs are affected by early unwinding, see Cheng, Fung, and Pang (1998).

where $F_0^- > F_0$. The no-arbitrage region is where $F_0^- \leq F_0 \leq F_0^+$. We also examine the distribution of the magnitude (absolute value) of the errors, disregarding their signs. The absolute value of the error is defined as e, where $e = e^+$ if $F > F^+$, $e = e^-$ if $F < F^-$, and $e = 0$ otherwise.[10] Because every FTSE-100 futures contract is hedged by 2.5 pairs of call and put options, the total spread cost for the execute-and-hold strategy is equal to a one-way spread for the futures contract and 2.5 times the one-way spread for both the call and option contracts.[11] The total spread cost for the execute-and-hold strategy can be written as

$$\psi_0 = \psi_0^{\mathrm{f}} + 2.5(\psi_0^{\mathrm{c}} + \psi_0^{\mathrm{p}}) \tag{6}$$

where ψ_0^{f}, ψ_0^{c}, and ψ_0^{p} are the one-way spread costs for trading one futures, one call, and one put option contract, respectively.

The total trading cost for the strategy involves a one-way trading fee for the futures contract[12] and 2.5 times the one-way trading fee for both options. The options may be exercised (depending on prices) so that the closing transaction may incur the cost of the call or the put. The maximum total trading cost of the strategy can be written as

$$\tau_0 = \tau_0^{\mathrm{f}} + 2.5(\tau_0^{\mathrm{c}} + \tau_0^{\mathrm{p}} + \tau_0^{\varphi}) \tag{7}$$

where τ_0^{f} is the round-trip trading cost for one futures contract, τ_0^{c} and τ_0^{p} are the opening trading costs for the call and put options, and τ_0^{φ} is the closing transaction cost for one option contract.

Arbitrage Triggers for the Early-Unwinding Strategy

An arbitrage position can be unwound profitably upon a reversal of sign of the initial error (Brennan & Schwartz, 1990; Merrick, 1989) if the magnitude of the (current) mispricing exceeds the marginal cost of early unwinding. Cheng et al. (1998) applied an early-unwinding strategy in the context of index futures versus index options arbitrage. They found the strategy provided incremental profits over the static held-to-maturity strategy. Unwinding an arbitrage portfolio before expiration involves taking opposite positions in all the contracts in the initial portfolio. This

[10] See Fung and Draper (1999, footnote 5).

[11] Multiplying by 2.5 converts the option spread points into futures spread points because one point for the FTSE-100 futures is worth £25 whereas one point for the FTSE-100 (ESX) options is worth only £10.

[12] There is no distinction between one-way and round-trip trading fees for the futures because the participant is always charged the round-trip fee.

incurs extra spread and trading costs. If the marginal spread and trading costs are ψ_1 and τ_1 on day t_1 (where $t_0 < t_1 < T$), respectively, then an initial short-futures arbitrage position can be unwound profitably if the fair futures price (F_1^*) less the actual futures price (F_1) at t_1 is greater than the spread and trading costs:

$$F_1^* - F_1 \geq \psi_1 + \tau_1 \tag{8}$$

where $F_1^* > F_1$. The total profit from unwinding the initial short-futures position will be equal to

$$e^+ + (F_1^* - F_1) - (\psi_1 + \tau_1) \tag{9}$$

An initial long-futures arbitrage position can be closed out profitably before T if

$$F_1 - F_1^* \geq \psi_1 + \tau_1 \tag{10}$$

where $F_1 > F_1^*$. The total profit from early unwinding of the long-futures portfolio is equal to

$$e^- + (F_1 - F_1^*) - (\psi_1 + \tau_1) \tag{11}$$

The marginal spread cost for early unwinding is equal to one extra one-way spread cost for one futures contract and 2.5 times the one-way spread costs for the options pair. That is,

$$\psi_1 = \psi_0^{\mathrm{f}} + 2.5(\psi_0^{\mathrm{c}} + \psi_0^{\mathrm{p}}). \tag{12}$$

The marginal trading cost for early unwinding includes 2.5 times the one-way trading costs for the options pair but saves the closing cost for either option, which was already accounted for in setting up the initial portfolio. Hence, the marginal cost is simply equal to 2.5 times the closing cost of one option position so that $\tau_1 = 2.5 \times (\tau_0^{\varphi})$.

DATA AND METHODOLOGY

Data

The LIFFE introduced the FTSE-100 Index futures and American-style (SEI) options contract in May 1984. A European-style (ESX) FTSE-100 Index option commenced trading on February 1, 1990. Delivery months for the futures contract are March, June, September, and December, and the contract multipliers for the futures and options contracts are £25 and £10 per index point, respectively. The difference between the multiplier values implies that every five pairs of ESX options can be hedged by two futures contracts. However, despite the difference in multiplier values, the parity condition for the FTSE contracts is identical to Equation 1.[13] The FTSE-100 futures and the ESX options contracts expire on the same day of the delivery month. The last trading day of both contracts prior to June 1992 was the last business day of the month. After June 1992, the last trading day is the third Friday in the delivery month (Sutcliffe, 1997, pp. 31–33). This study focuses on the near-month futures contract because it is most liquid. However, as the maximum time to maturity of the contract is 3 months, the options contracts of the 3 nearest calendar months are adopted to match the maturity of the futures contract.

LIFFE provides time-stamped, firm bid and offer quotes as well as traded prices for the FTSE-100 options (ESX) and the FTSE-100 futures contracts. The data permit matching of the traded prices of the contracts within narrow time intervals of 1 min, reducing the nonsynchronous price problems of previous research that used closing prices.

Time-stamped, intraday bid-and-ask quotes and transaction price records were obtained from LIFFE Data Services for the period October 1, 1991 to February 20, 1998. The data were extracted from CD-ROMs containing the tick data for Sterling products (i.e., the Sterling Products Tick data).[14] London interbank offered rates (LIBOR) retrieved from DataStream are used as the risk-free interest rates. Five rates are used: overnight; 1 week; and 1, 2, and 3 months. If the expiration date of the contract does not match the maturity date of the relevant interest rates, the appropriate interest rate is interpolated. If, for example, the contracts expire in 1.5 months, a rate based on the 1- and 2-month rates is used for the calculation.

The time-stamped, traded-price record allows us to create put–call–futures price trios that are synchronous within a 1-min time period. Given a traded call price, we search for a put option with the same exercise price and a futures contract traded within 1 min of the call. No trio is formed if the difference in trading time between prices exceeds 1 min.

Trios that produce large pricing errors (within the top 1%) are checked with the source file to examine whether the error is due to typographical problems. Two major sources of errors are customary and arise

[13]The payoff table is identical to the one shown in Fung et al. (1997), except that the hedge portfolio is now composed of two futures contracts and five pairs of call and put options.

[14]The data are managed and analyzed with SAS and Turbo C programs.

from missing or adding one zero in the number string and flip-flopping the put and call prices. Questionable trios are rejected because their validity cannot be verified. Our procedure is biased toward rejecting observations with large pricing errors. Using the 1-min matching procedure and the filtering criteria, we obtain 6,296 matched price trios for the sample period.

The round-trip trading cost for one futures contract is estimated to be £50.[15] The commission cost for opening an option position is estimated to be £22.50, and LIFFE also charges £1.80 per contract for opening and closing. The closing cost for an option position is estimated to be £12.50 in addition to the exchange charge. The total trading cost per arbitrage portfolio (which contains one futures contract and 2.5 pairs of puts and calls) for the execute-and-hold strategy is estimated to be 7.25 futures points. Because the total exchange charges for members (broker dealers) are only a small fraction of a point, the trading cost for members is ignored. The cost to members is restricted to the spread cost only. The cost to nonmembers is equal to the spread cost plus the trading cost. If we assume that the trades are executed at the middle of the bid-and-ask quotes, the one-way percentage spread cost per transaction in the contracts is calculated according to the following formula (see ap Gwilym, Buckle & Thomas, 1997; Yadav & Pope, 1994):

$$\frac{\text{Ask}}{(\text{Ask} + \text{Bid})/2} - 1 \tag{13}$$

For the options contracts, the bid-and-ask prices are quoted side by side. To control for the influence of time to maturity and the moneyness of the contracts on the magnitude of the spread, we sort the contracts for any particular day into three different maturities: less than 30 days, between 30 and 60 days, and greater than 60 days. For each maturity series, the contracts are further sorted according to the moneyness of the contract. The contracts are classified into at-the-money, near-the-money, and far-from-the-money contracts. Moneyness of the contract is defined by the ratio F/X.[16] The average percentage spread of contracts within a maturity-moneyness category is used as the percentage one-way spread for contracts within the category. Hence, we obtain nine different percentage spreads for both the call and the put on each relevant trading

[15]This figure is taken from Yadav and Pope (1990). Because trading costs have, on the whole, been falling over this period, this is a conservative estimate.

[16]The fraction F/X is used to define moneyness because the asset that is hedged by the options contracts is the futures contract. At-the-money is defined as $0.95 \leq F/X \leq 1.05$, near-the-money is defined as $0.85 \leq F/X < 0.95$ and $1.05 < F/X \leq 1.15$, and far-from-the-money is defined as $F/X < 0.85$ and $1.15 < F/X$.

day. The magnitude of the one-way spread for a particular traded price is equal to the price multiplied by the stipulated percentage spread for the contract that belongs to the particular category.

For the futures contracts, because bid-and-ask prices are not quoted parallel to each other, we first calculate a percentage spread by matching the bid price with the nearest ask price for a future with identical maturity. Bid-and-ask price pairs with time lags in excess of 1 min are discarded from the sample. As with the options quotes, the contracts are classified into three different categories according to their remaining days to maturity (within 30 days, more than 30 days and less than 60 days, and more than 60 days). For each trading day, we then obtain the percentage spread for futures within each category by taking the average. The (absolute) one-way spread cost for a futures contract of a particular maturity is then equal to the futures price multiplied by the (average) percentage spread for the maturity subgroup for that particular day.[17]

The average one-way spread cost for the futures is estimated to be 0.82 futures points (Table I). The spread cost for the call and put options are calculated to be 4.31 and 3.93 options points, respectively. The total spread cost per arbitrage trade is estimated to range from 2.82 (for short-maturity contracts) to 5.01 (for long-maturity contracts) futures points with the at-the-money options (see Table II). Moreover, Table II shows that the spread cost for trading far-from-the-money or near-the-money options is considerably higher than the spread costs for at-the-money trading.

Using the derived ex-post execute-and-hold error series, we use Klemkosky and Lee's (1991) ex-ante simulation method to study the dynamic efficiency of the error series by factoring in a range of possible execution time lags. We examine five different time lags: within 3 min, between 3 and 5 min, between 5 and 10 min, between 10 and 15 min, and between 15 and 30 min. We also use early-unwinding simulation tests[18] to detect whether dynamic trading strategies might improve the profitability of put–call–futures arbitrage.

To examine the factors that affect the magnitude of the ex-post pricing error (e) under the three different cost regimes, the error is regressed against a number of variables. These include the total spread cost (ψ), the volatility[19] (σ), the time to maturity of the contracts in days (t), the

[17]Following Yadav and Pope (1990, p. 578), for each trading day we take the average of all ask and bid quotes for the near contract. We then use these values to estimate the bid–ask spread applicable on that day.

[18]See Merrick (1989), Finnerty and Park (1988), Brennan and Schwartz (1990), and, particularly, Cheng et al. (1998), who directly applied the early-unwinding strategy to options–futures arbitrage.

[19]For each futures price, we have two implied volatilities; one due to the call and the other due to the put. An average of the two implied volatilities is used as our estimate.

TABLE I

Descriptive Statistics for the Spread Cost on Different Kinds of Derivative Contracts (in Futures Points for the Futures Contract and in Options Points for the Call and Put)

	Futures	*Call*	*Put*
N	6,296	6,296	6,296
M	0.82	4.31	3.93
SD	0.20	7.17	5.16
Maximum	1.99	105.29	71.24
Mdn	0.79	2.47	2.85
Minimum	0.43	0.04	0.04

TABLE II

Descriptive Statistics for the Total Spread Cost on Arbitrage Trade (in Futures Points)

		At-the-Money			*Near-the-Money*			*Far-From-the-Money*		
	Overall	$t \leq 30$	$30 < t \leq 60$	$60 < t$	$t \leq 30$	$30 < t \leq 60$	$60 < t$	$t \leq 30$	$30 < t \leq 60$	$60 < t$
N	6,296	3,007	2,011	897	105	154	36	29	30	27
M	4.12	2.82	4.93	5.01	6.41	7.85	6.07	13.49	12.17	7.42
SD	4.41	1.26	5.07	7.19	2.67	4.50	2.71	3.91	4.90	0.79
Maximum	55.93	10.09	31.89	55.93	11.55	21.37	9.09	20.16	18.95	8.82
Mdn	3.10	2.53	3.36	3.47	6.34	6.59	6.69	11.11	8.89	7.25
Minimum	0.87	0.87	1.89	1.94	2.81	2.51	3.01	10.77	5.29	5.91

Note. *t* indicates the days to maturity common to the matched futures and options trios.

moneyness of the contract ($L = |F - X|/X$), a dummy variable to see whether profitability differs between call contracts that are in-the-money or out-of-the-money (if $F > X$, $D_1 = 1$; otherwise, $D_1 = 0$), and a dummy variable to distinguish between the long-futures and short-futures strategies ($D_2 = 1$ for the short-futures strategy and $D_2 = 0$ for the long-futures strategy):

$$e = \alpha + \beta_1\psi + \beta_2\sigma + \beta_3 t + \beta_4 L + \beta_5 D_1 + \beta_6 D_2 + \varepsilon \qquad (14)$$

The magnitude of the ex-post pricing error under the different cost regimes will be affected by a variety of different factors, including spread costs and volatility. Larger spread costs, for example, indicate greater uncertainty in pricing. A positive relationship may be expected between spread costs and mispricing. The larger the spread is, the greater the uncertainty and, therefore, mispricing are. A similar relationship may be expected for volatility. Increases in volatility will reflect increased pricing uncertainty and, hence, suggest larger errors. We would again expect a positive relationship between mispricing errors and volatility.

Put–call–futures parity must hold at expiration. Consequently, the ability of the contracts to fluctuate around their values as implied by the parity condition is positively related to time to expiration, so we would expect the error to be positively related to time to maturity. Option traders use futures to hedge their options positions. The moneyness of an option is a proxy for its liquidity and the size of the bid–ask spread. Arbitrage with less liquid options will be more risky because of lower liquidity and will be associated with a higher cost because of the bigger spread. Hence, a positive coefficient for moneyness is expected.

EMPIRICAL FINDINGS

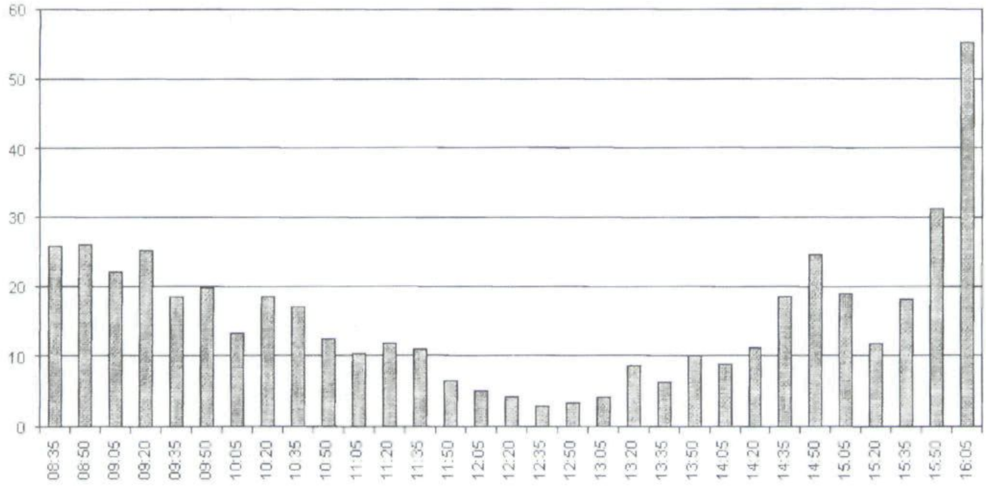
Ex-Post Results

Trading via open outcry at LIFFE took place from 8:35 to 16:10 Greenwich Mean Time (GMT).[20] To explore the intraday distribution, following the approach of ap Gwilym et al. (1997) and ap Gwilym, Clare, and Thomas (1998), we divide the trading day into thirty 15-min intervals and one 5-min interval. The first interval is between 8:35 and 8:50 GMT, the second interval is between 8:50 to 9:05 GMT, and the intervals continue in this fashion until the 30th interval from 15:50 to 16:05. The final interval includes the last 5 min of trading between 16:05 and 16:10. The number of matched put–call–futures trios within an interval is divided by the number of minutes for the particular interval. The number of observations for the first 30 intervals is divided by 15 and for the last interval is divided by 5. Figure 1 illustrates the distribution of matched put–call–futures trios during the day. Each bar in our figure represents the number of trios per minute within the interval. The histogram shows a clear U-shaped pattern with a higher (per minute) count of matched trios at the open and close of the trading session. A regression model is used to test for the statistical significance of the intraday pattern. The average number of observations (per minute) within an interval (O_t) is regressed against dummy variables representing the 1st (D_1), 30th (D_{30}), and 31st (D_{31}) intervals:

$$O_t = \alpha_0 + \alpha_1 D_1 + \alpha_2 D_{30} + \alpha_3 D_{31} + \varepsilon_t \qquad (15)$$

The results (Table III) reveal that the estimated coefficients are positive and statistically significant. The number of matched trios has a much greater concentration at the close, and to a lesser degree at the open, than during the rest of the day.

[20]The automated pit trading session after 16:32 GMT is discarded from the sample.



Note. Trading via open outcry at LIFFE was conducted between 8:35 and 16:10 GMT. We divide a trading day into thirty 15-min intervals and one 5-min interval. The first interval is between 8:35 and 8:50 GMT, the second interval is between 8:50 and 9:05 GMT, and the intervals continue in this fashion until the 30th interval between 15:50 and 16:05 GMT. The last interval covers the last 5 min of trading and is set between 16:05 and 16:10 GMT. The automated pit trading session from 16:32 to 17:30 GMT is discarded from the sample. We then divide the number of matched put–call–futures trios within an interval by the number of minutes for the particular interval. The number of observations for the first 30 intervals are divided by 15, and that for the last interval is divided by 5 because the last interval is only 5 min long.

FIGURE 1

Intraday distribution of the number of matched trios per minute within an interval.

TABLE III

Regression Test of the Statistical Significance of the Intraday Pattern on the Number of Matched Trios

Dependent Variable	*N*		*Constant*	D_1	D_{30}	D_{31}	R^2	*F*
O_t	31	Estimates	13.18571	12.68	18.08	42.08	0.6165	14.47
		p	<0.0001	0.0832	0.0162	<0.0001		<0.0001

Note. To test for the intraday pattern on the number of matched trios, following ap Gwilym, Buckle, and Thomas (1997), we divide a trading day (from 8:35 GMT to 16:10 GMT) into thirty 15-min intervals and one 5-min interval. The first interval is between 8:35 and 8:50 GMT, the second interval is between 8:50 and 9:05 GMT, and the intervals continue in this fashion until the 30th interval between 15:50 and 16:05. The last interval covers the last 5 min of trading between 16:05 and 16:10. The automated pit trading session from 16:32 GMT is discarded from the sample. We divide the number of matched put–call–futures trios within an interval by the number of minutes for the particular interval. The number of observations is divided for the first 30 intervals by 15 and for the last interval by 5, the following model we adopted to test for the statistical significance of the intraday pattern:

$$O_t = \alpha_0 + \alpha_1 D_1 + \alpha_2 D_{30} + \alpha_3 D_{31} + \varepsilon_t$$

O_t denotes the average number of observations each minute within an interval $t(t = 1\text{–}31)$. D_1, D_{30}, and D_{31} are dummy variables that signify the first and last two intervals, respectively. D_i is equal to 1 if an observation falls into the ith interval and is equal to zero otherwise. The number of matched trios has a much greater concentration at the close and to a lesser degree at the open than during the rest of the day.

Panel A of Table IV shows the ex-post arbitrage profits if zero transaction costs are assumed. The average profit for all trades is 3.95 index points. Long-futures arbitrage opportunities, on average, are less profitable than short-futures opportunities (3.88 points for the long futures and 4.02 for the short futures). Long-futures arbitrage opportunities occur slightly more frequently (3,261) than short-futures opportunities (3,035). Most opportunities are concentrated in at-the-money options.

Table IV also reveals that profits increase with time to maturity. With zero transaction costs, the average profit is 3.35 points when the time to maturity is less than 30 days and 4.42 points when the time to maturity is greater than 30 days for the at-the-money contract. For the zero-cost far-from-the-money contract, the position is reversed. The average profit is 7.31 points when the time to maturity is less than 30 days and 5.52 points when the time to maturity is greater than 60 days.

Similar findings occur for the member (of the exchange) and nonmember cost categories for at-the-money transactions. Panels B and C of Table IV, for levels of transaction costs associated with members and nonmembers (high transaction costs), indicate that arbitrage opportunities are concentrated in at-the-money options ,with very few opportunities near-the-money or far-from-the-money. The potential profitability of the opportunities increases with time to maturity with average profits for members for at-the-money contracts of 3.29 points when the time to maturity is less than 30 days and 3.38 points when the time to maturity is greater than 60 days. For nonmembers, the average profit is 8.21 points when the time to maturity is less than 30 days and 13.98 points when the time to maturity is greater than 60 days, although the number of opportunities is small.

Ex-post arbitrage profits for the long-futures strategy are, on average, similar to those for the short-futures strategy. The ex-post average arbitrage profits of a member for the long-futures strategy is 3.17 points, compared with 3.82 points for the short-futures strategy. Similar conclusions hold for nonmembers.

The intraday pattern of mispricings is also of interest. Ap Gwilym et al. (1998) found that the spreads on the FTSE-100 Index futures and (American-style) option on the FTSE-100 Index are wider at the open and narrower at the close. This might suggest that the apparent mispricings should be larger at the open than at the close. Figure 2 provides a plot of the intraday distribution of the pricing errors. As with the U-shaped pattern of the intraday distribution of the matched number of trios, observed pricing errors are also bunched around the opening and closing times of the trading sessions. To examine directly whether there

TABLE IV

Ex-Post Arbitrage Profit (in Points) Under the Execute-and-Hold Strategy

		At-the-Money			Near-the-Money			Far-From-the-Money		
	Overall	$t \leq 30$	$30 < t \leq 60$	$60 < t$	$t \leq 30$	$30 < t \leq 60$	$60 < t$	$t \leq 30$	$30 < t \leq 60$	$60 < t$
					Panel A: Zero Cost					
e										
N	6,296	3,007	2,011	897	105	154	36	29	30	27
M	3.95	3.35	4.42	4.27	3.41	6.51	8.17	7.31	2.10	5.52
SD	5.91	5.06	7.00	5.97	2.83	5.50	5.83	6.12	1.33	4.97
Maximum	60.02	60.02	55.87	49.62	14.42	24.48	17.20	15.45	4.27	14.97
Mdn	2.31	2.01	2.33	2.86	3.04	5.32	6.76	4.77	2.10	4.13
Minimum	0.00	0.00	0.00	0.01	0.13	0.01	0.09	0.10	0.24	0.25
e^+										
N	3,035	1,508	907	428	63	80	14	17	11	7
M	4.02	3.21	4.74	4.82	3.58	5.37	10.16	8.99	2.21	2.89
SD	6.41	4.39	8.55	7.53	2.07	3.38	5.58	5.89	1.10	1.82
Maximum	55.87	52.00	55.87	49.62	8.03	11.29	15.67	15.45	4.10	4.13
Mdn	2.10	2.00	2.19	2.77	3.04	5.22	12.17	12.45	2.10	4.13
Minimum	0.00	0.00	0.02	0.01	0.13	0.04	0.09	0.90	0.67	0.27
e^-										
N	3,261	1,499	1,104	469	42	74	22	12	19	20
M	3.88	3.48	4.16	3.76	3.16	7.73	6.90	4.93	2.03	6.45
SD	5.40	5.66	5.40	4.00	3.71	6.94	5.74	5.87	1.47	5.41
Maximum	60.02	60.02	44.93	27.58	14.42	24.48	17.20	13.78	4.27	14.97
Mdn	2.53	2.05	2.43	3.00	1.54	5.34	5.76	2.16	1.50	5.09
Minimum	0.00	0.00	0.00	0.03	0.41	0.01	0.91	0.10	0.24	0.25
					Panel B: Member					
e										
N	2,492	1,347	679	353	24	56	16	11	n.a.	6
M	3.48	3.29	3.91	3.38	2.54	2.09	9.30	2.65	n.a.	6.72
SD	6.06	6.40	5.42	6.51	3.27	1.45	1.81	1.28	n.a.	0.63
Maximum	58.54	58.54	35.91	41.27	10.26	6.73	12.66	4.35	n.a.	7.72
Mdn	1.72	1.66	1.76	1.82	1.42	1.83	8.71	3.35	n.a.	6.72
Minimum	0.01	0.01	0.01	0.03	0.06	0.11	5.71	0.55	n.a.	5.72
e^+										
N	1,187	648	303	176	13	27	11	9	n.a.	n.a.
M	3.82	3.14	4.94	4.40	1.42	2.67	9.84	3.12	n.a.	n.a.
SD	6.18	5.05	6.90	8.64	0.84	1.57	1.78	0.83	n.a.	n.a.
Maximum	46.55	46.55	35.91	41.27	2.42	6.73	12.66	4.35	n.a.	n.a.
Mdn	1.78	1.65	2.17	2.19	1.42	2.65	9.66	3.35	n.a.	n.a.
Minimum	0.01	0.01	0.05	0.03	0.06	0.21	7.66	1.35	n.a.	n.a.
e^-										
N	1,305	699	376	177	11	29	5	2	n.a.	6
M	3.17	3.42	3.08	2.36	3.86	1.55	8.11	0.55	n.a.	6.72
SD	5.92	7.44	3.64	2.89	4.49	1.11	1.34	0.00	n.a.	0.63
Maximum	58.54	58.54	15.63	19.70	10.26	3.52	8.71	0.55	n.a.	7.72
Mdn	1.66	1.71	1.49	1.73	1.43	1.52	8.71	0.55	n.a.	6.72
Minimum	0.01	0.03	0.01	0.03	0.43	0.11	5.71	0.55	n.a.	5.72

(Continued)

TABLE IV
(Continued)

	Overall	At-the-Money $t \leq 30$	At-the-Money $30 < t \leq 60$	At-the-Money $60 < t$	Near-the-Money $t \leq 30$	Near-the-Money $30 < t \leq 60$	Near-the-Money $60 < t$	Far-From-the-Money $t \leq 30$	Far-From-the-Money $30 < t \leq 60$	Far-From-the-Money $60 < t$
Panel C: Nonmember										
e										
N	294	135	114	26	3	n.a.	15	n.a.	n.a.	1
M	7.53	8.21	6.13	13.98	3.01	n.a.	2.29	n.a.	n.a.	0.47
SD	11.98	14.85	7.01	14.17	0.00	n.a.	1.59	n.a.	n.a.	n.a.
Maximum	51.29	51.29	28.66	34.02	3.01	n.a.	5.41	n.a.	n.a.	0.47
Mdn	3.20	2.39	4.76	10.70	3.01	n.a.	1.46	n.a.	n.a.	0.47
Minimum	0.04	0.04	0.10	0.26	3.01	n.a.	0.41	n.a.	n.a.	0.47
e^{+}										
N	165	73	65	16	n.a.	n.a.	11	n.a.	n.a.	n.a.
M	7.60	5.28	7.99	20.02	n.a.	n.a.	2.59	n.a.	n.a.	n.a.
SD	10.63	10.19	8.53	14.63	n.a.	n.a.	1.78	n.a.	n.a.	n.a.
Maximum	39.30	39.30	28.66	34.02	n.a.	n.a.	5.41	n.a.	n.a.	n.a.
Mdn	3.21	2.35	4.80	30.52	n.a.	n.a.	2.41	n.a.	n.a.	n.a.
Minimum	0.10	0.21	0.10	0.47	n.a.	n.a.	0.41	n.a.	n.a.	n.a.
e^{-}										
N	129	62	49	10	3	n.a.	4	n.a.	n.a.	1
M	7.44	11.66	3.65	4.31	3.01	n.a.	1.46	n.a.	n.a.	0.47
SD	13.56	18.43	2.78	5.65	0.00	n.a.	0.00	n.a.	n.a.	n.a.
Maximum	51.29	51.29	8.38	12.45	3.01	n.a.	1.46	n.a.	n.a.	0.47
Mdn	2.81	3.21	3.19	1.23	3.01	n.a.	1.46	n.a.	n.a.	0.47
Minimum	0.04	0.04	0.31	0.26	3.01	n.a.	1.46	n.a.	n.a.	0.47

Note. Panel A shows the ex-post arbitrage profits with zero transaction costs. Panels B and C show the ex-post arbitrage profits with levels of transaction costs associated with members and nonmembers (high transaction costs). They indicate that arbitrage opportunities are concentrated in at-the-money options with very few opportunities near-the-money or far-from-the-money. The potential profitability of the opportunities increases with the time to maturity.
n.a. = not applicable.

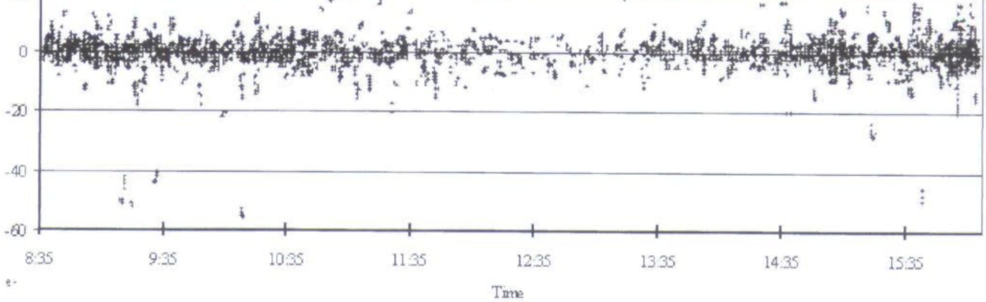


FIGURE 2
Intraday scatter of pricing errors at zero transaction cost.

is any significant difference in the magnitudes of the errors observed at the open or at the close and those observed at other times of the day, we regress the magnitude of the pricing error (e_t) at time t on dummy variables representing the 1st, 30th, and 31st intervals. Intervals are defined as for Equation 15:

$$e_t = \alpha_0 + \alpha_1 D_1 + \alpha_2 D_{30} + \alpha_3 D_{31} + \varepsilon_t \tag{16}$$

Table V summarizes the regression results. The estimated coefficients for all the dummy variables are statistically insignificant. This suggests that the average magnitude of the errors at the open and close is not significantly different from the sample mean.

Panel A of Table VI shows the ex-ante arbitrage profit from an execute-and-hold strategy with zero transaction costs (Klemkosky & Lee, 1991). Across all categories of lags, arbitrage trades are significantly profitable only if the transactions are executed within a 15-min time lag (3.92 points if the lag is less than 3 min). However, when the time lag increases to more than 3 min, the magnitude of the arbitrage profit decreases substantially. More importantly perhaps, the number of mispricing opportunities that last longer than 3 min becomes small. The majority of the ex-ante opportunities are concentrated in the near end when the options are liquid. The results suggest a negative relationship between the magnitude of arbitrage profit and the execution time lag and indicate that the market is dynamically efficient with price adjustments to correct for pricing errors completed in less than 5 min.

Comparing profitability, given the execution time lags between the long-future arbitrage opportunities and the short-future arbitrage opportunities, we find that, on average, the ex-ante average long-future

TABLE V

Regression Test of the Intraday Pattern on the Average Magnitude of Mispricings

Dependent Variable	*N*		*Constant*	D_1	D_{30}	D_{31}	R^2	*F*
e_t	6,296	Estimates	4.04845	0.43631	−0.00723	−0.16557	0.0001	0.24
		p	<0.0001	0.4223	0.9902	0.8290		0.8679

Note.

$$e_t = \beta_0 + \beta_1 D_1 + \beta_2 D_{30} + \beta_3 D_{31} + \varepsilon_t$$

e_t denotes the magnitude of a pricing error observed at time t. D_1, D_{30}, and D_{31} are dummy variables that signify the first and last two intervals, respectively. D_i is equal to 1 if an observation falls into the ith interval (i = 1, 30, and 31) and is equal to zero otherwise. The estimated coefficients for all the dummy variables are statistically insignificant. This suggests that the average magnitude of the errors at the open and close is not significantly different from the sample mean.

TABLE VI

Ex-Ante Arbitrage Profit (in Points) Under the Execute-and-Hold Strategy

	Overall	*Lag < 3 min*	*3 min ≤ Lag < 5 min*	*5 min ≤ Lag < 10 min*	*10 min ≤ Lag < 15 min*	*15 min ≤ Lag < 30 min*
			Panel A: Zero Cost			
All signal						
N	6,296	5,020	222	384	213	457
M	3.32	3.92	2.23	1.59	0.60	0.04
(*t* value)	(43.58)	(45.08)	(9.13)	(6.22)	(2.58)	(0.16)
SD	6.18	6.29	3.72	5.16	3.47	6.01
Maximum	59.02	59.02	14.98	25.40	9.91	15.05
Mdn	2.06	2.67	1.99	1.03	0.95	0.24
Minimum	−16.01	−12.00	−6.30	−5.97	−10.77	−16.01
Short-futures signal						
N	3,318	2,625	156	205	97	236
M	3.30	3.88	2.69	1.78	1.04	−0.45
(*t* value)	(32.89)	(34.47)	(15.08)	(4.45)	(2.74)	(−1.07)
SD	5.90	5.88	2.27	5.84	3.83	6.63
Maximum	59.02	59.02	8.58	25.40	9.91	14.34
Mdn	2.33	2.86	2.32	1.98	0.95	−0.01
Minimum	−16.01	−11.05	−1.37	−5.97	−10.77	−16.01
Long-futures signal						
N	2,978	2,395	66	179	116	221
M	3.35	3.97	1.17	1.39	0.23	0.57
(*t* value)	(28.83)	(29.55)	(1.70)	(4.50)	(0.82)	(1.66)
SD	6.47	6.70	5.74	4.29	3.11	5.23
Maximum	55.87	55.87	14.98	13.23	6.03	15.05
Mdn	2.00	2.30	−0.97	0.22	0.95	0.99
Minimum	−14.34	−12.00	−6.30	−4.05	−9.91	−14.34
			Panel B: Member			
All signal						
N	246	220	2	5	12	7
M	3.47	5.13	−1.90	−9.92	−10.23	−14.21
(*t* value)	(4.04)	(5.90)	(.)	(−2.38)	(−10.89)	(−2.50)
SD	13.45	12.91	0.00	9.31	3.25	15.04
Maximum	51.52	51.52	−1.90	0.28	−5.82	−2.15
Mdn	2.28	2.83	−1.90	−16.71	−12.43	−2.15
Minimum	−64.44	−64.44	−1.90	−16.71	−12.43	−30.29
Short-futures signal						
N	104	93	2	2	n.a.	7
M	6.20	8.04	−1.90	0.28	n.a.	−14.21
(*t* value)	(3.91)	(5.00)	(.)	(.)		(−2.50)
SD	16.16	15.50	0.00	0.00	n.a.	15.04
Maximum	51.52	51.52	−1.90	0.28	n.a.	−2.15
Mdn	2.55	2.59	−1.90	0.28	n.a.	−2.15
Minimum	−30.29	−9.92	−1.90	0.28	n.a.	−30.29

(Continued)

TABLE VI
(Continued)

	Overall	*Lag < 3 min*	*3 min ≤ Lag < 5 min*	*5 min ≤ Lag < 10 min*	*10 min ≤ Lag < 15 min*	*15 min ≤ Lag < 30 min*
Long-futures signal						
N	142	127	n.a.	3	12	n.a.
M	1.47	3.00	n.a.	−16.71	−10.23	n.a.
(*t* value)	(1.64)	(3.33)		(.)	(−10.89)	
SD	10.68	10.17	n.a.	0.00	3.25	n.a.
Maximum	30.45	30.45	n.a.	−16.71	−5.82	n.a.
Mdn	2.12	2.83	n.a.	−16.71	−12.43	n.a.
Minimum	−64.44	−64.44	n.a.	−16.71	−12.43	n.a.

Note. The table is constructed as follows. Assume that a signal arrives to short the call, long the put, and long the futures. The program searches for puts and calls that can be matched with the future. If it finds that such a match could have taken place after *m* minutes, the profit/loss of the strategy based on the traded prices of the trio is calculated and the search stops. Across all categories of lags, arbitrage trades are significantly profitable only if the transactions are executed within 15-min time lag. When the time lag increases to more than 3 min, the magnitude of the arbitrage profit decreases substantially. The number of mispricing opportunities that last longer than 3 min is small.
n.a. = not applicable.

arbitrage opportunities with zero costs assumed are marginally more profitable but occur less frequently than short-futures opportunities (3,318 for short futures and 2,978 for long futures). The standard deviation of the long-futures profit is also greater. When the time lag exceeds 10 min, the pricing error of long-futures arbitrage is negative and drops substantially. However, for the short-futures arbitrage, the pricing error decreases more slowly.

Panel B of Table VI shows the ex-ante arbitrage profit for the execute-and-hold strategy for the level of transaction costs associated with members. Trades with an execution time lag of less than 3 min are profitable (5.13 points). It is also apparent that the ex-ante average long-future arbitrage opportunities are less profitable at 3.00 points but occur more frequently than short-futures (8.04 points) opportunities.[21]

Tables VII and VIII show the distribution of the arbitrage profit with the early-unwinding strategy under zero-cost and member-cost assumptions, respectively. Table VII reveals that 4,855 out of 6,296 positions (77%) could be successfully unwound if there were zero transaction costs. The largest number of opportunities is in at-the-money, near-maturity options, where liquidity is greatest and it is easiest to unwind the initial position. In near-the-money or far-from-the-money options, it is difficult to unwind the positions. After unwinding, the average total profit, which consists of the initial profit plus the additional profit upon unwinding,

[21]Very few profitable opportunities occur with high (nonmember) transaction costs, and all are quickly extinguished. For this reason, the table is omitted.

TABLE VII

Arbitrage Profit (in Points) for Zero Cost Under the Early-Unwinding Strategy

		At-the-Money			Near-the-Money			Far-From-the-Money		
	Overall	$t \leq 30$	$30 < t \leq 60$	$60 < t$	$t \leq 30$	$30 < t \leq 60$	$60 < t$	$t \leq 30$	$30 < t \leq 60$	$60 < t$
Initial profit										
N	4,855	2,211	1,706	790	30	78	24	4	7	5
M	3.59	3.16	3.71	4.22	3.53	5.30	9.89	2.57	0.78	3.93
	(52.20)	(35.93)	(31.98)	(19.08)	(5.68)	(13.45)	(7.69)	(2.67)	(4.47)	(19.66)
SD	4.79	4.13	4.79	6.21	3.41	3.48	6.31	1.92	0.46	0.45
Maximum	52.00	52.00	44.93	49.62	14.42	11.73	17.20	4.23	1.49	4.13
Mdn	2.09	2.00	2.19	2.77	3.26	5.32	12.17	2.57	0.67	4.13
Minimum	0.00	0.00	0.00	0.01	0.13	0.01	0.09	0.90	0.33	3.13
Additional profit upon unwinding										
N	4,855	2,211	1,706	790	30	78	24	4	7	5
M	2.13	2.10	2.04	2.18	2.13	4.07	3.11	1.93	1.09	0.25
	(43.48)	(28.97)	(32.38)	(12.86)	(6.27)	(12.98)	(8.58)	(1.83)	(2.97)	(n.a.)
SD	3.41	3.41	2.60	4.77	1.86	2.77	1.77	2.12	0.98	0.00
Maximum	50.18	26.99	23.52	50.18	7.85	10.05	10.99	3.77	3.20	0.25
Mdn	1.02	1.00	1.08	1.11	1.46	4.56	2.92	1.93	0.90	0.25
Minimum	0.00	0.00	0.01	0.00	0.55	0.01	0.91	0.10	0.33	0.25
Total profit										
N	4,855	2,211	1,706	790	30	78	24	4	7	5
M	5.715	5.26	5.75	6.40	5.66	9.37	13.00	4.50	1.87	4.18
	(61.82)	(43.11)	(41.97)	(19.34)	(9.09)	(18.88)	(10.06)	(2.23)	(3.75)	(20.89)
SD	6.442	5.73	5.65	9.30	3.41	4.39	6.33	4.04	1.32	0.45
Maximum	77.77	53.06	45.74	77.77	15.37	17.01	20.15	8.00	4.69	4.38
Mdn	4	3.88	4.03	5.00	5.02	9.74	15.09	4.50	1.23	4.38
Minimum	0.014	0.01	0.21	0.50	1.00	1.00	1.00	1.00	1.00	3.38
e^+ (initial short-futures arbitrage position)										
N	2,558	1,075	1,011	410	10	34	11	2	5	n.a.
M	5.50	4.93	5.80	5.84	6.83	8.19	12.40	8.00	2.22	n.a.
	(44.67)	(37.78)	(28.89)	(12.67)	(6.23)	(10.66)	(5.75)	(n.a.)	(3.44)	n.a.
SD	6.23	4.27	6.38	9.34	3.47	4.48	7.16	0.00	1.44	n.a.
Maximum	77.77	27.99	45.74	77.77	15.37	14.77	20.15	8.00	4.69	n.a.
Mdn	4.00	3.94	4.00	4.65	6.01	9.00	11.90	8.00	1.71	n.a.
Minimum	0.05	0.05	0.39	0.50	4.02	1.00	5.15	8.00	1.23	n.a.
e^- (initial long-futures arbitrage position)										
N	2,297	1,136	695	380	20	44	13	2	2	5
M	5.96	5.57	5.67	7.00	5.08	10.29	13.50	1.00	1.00	4.18
	(42.82)	(27.54)	(34.07)	(14.79)	(6.85)	(16.52)	(8.42)	(n.a.)	(n.a.)	(20.89)
SD	6.67	6.82	4.39	9.22	3.32	4.13	5.78	0.00	0.00	0.45
Maximum	74.70	53.06	27.00	74.70	9.40	17.01	18.59	1.00	1.00	4.38
Mdn	4.00	3.80	4.29	5.08	4.93	10.71	15.59	1.00	1.00	4.38
Minimum	0.01	0.01	0.21	0.50	1.00	1.00	1.00	1.00	1.00	3.38

Note. Of the positions, 77% could be successfully unwound if there were zero transaction costs. The largest number of opportunities is in at-the-money, near-maturity options where liquidity is greatest and it is easiest to unwind the initial position. In near-the-money or far-from-the-money options, it is difficult to unwind the positions. After unwinding, the average total profit, which consists of the initial profit plus the additional profit upon unwinding, increases.
n.a. = not applicable.

TABLE VIII
Arbitrage Profit (in Points) for Member Under the Early-Unwinding Strategy

	Overall	At-the-Money		
		$t \leq 30$	$30 < t \leq 60$	$60 < t$
Initial profit				
N	253	193	40	20
M	3.89	2.32	3.96	18.90
	(8.94)	(13.06)	(7.24)	(4.99)
SD	6.92	2.46	3.46	16.92
Maximum	38.17	10.86	13.04	38.17
Mdn	1.69	1.47	2.49	14.61
Minimum	0.02	0.02	0.32	0.38
Additional profit upon unwinding				
N	253	193	40	20
M	2.89	2.97	3.61	0.74
	(9.07)	(7.84)	(4.41)	(3.68)
SD	5.07	5.26	5.18	0.90
Maximum	19.41	19.41	19.41	3.12
Mdn	0.93	0.93	1.46	0.25
Minimum	0.03	0.03	0.28	0.19
Total profit				
N	253	193	40	20
M	6.78	5.28	7.57	19.64
	(13.73)	(13.44)	(9.55)	(5.38)
SD	7.85	5.46	5.01	16.33
Maximum	38.36	22.55	19.74	38.36
Mdn	4.20	3.45	5.79	14.87
Minimum	0.22	0.22	1.58	1.16
e^+ (initial short-futures arbitrage position)				
N	102	85	10	7
M	4.72	3.97	9.10	7.58
	(14.76)	(16.49)	(10.87)	(2.94)
SD	3.23	2.22	2.65	6.83
Maximum	14.87	11.76	11.13	14.87
Mdn	3.97	3.45	11.13	2.86
Minimum	0.91	0.91	5.79	1.86
e^- (initial long-futures arbitrage position)				
N	151	108	30	13
M	8.17	6.32	7.06	26.14
	(10.48)	(9.56)	(7.00)	(5.75)
SD	9.58	6.87	5.52	16.38
Maximum	38.36	22.55	19.74	38.36
Mdn	4.26	3.40	5.26	35.36
Minimum	0.22	0.22	1.58	1.16

Note. The table shows the ex-ante arbitrage profit for the execute-and-hold strategy for the level of transaction costs associated with members. Trades with an execution time lag of less than 3 min are profitable.

TABLE IX
Holding Period (in Days) for Zero and Member Cost Under the Early-Unwinding Strategy

	Zero Cost	*Member Cost*
N	4,855	253
M	6.74	15.27
SD	11.87	20.57
Maximum	79.00	84.00
Mdn	1.00	6.00
Minimum	0.00	0.00
e^+ (initial short-futures arbitrage position)		
N	2,558	102
M	7.28	10.86
SD	12.13	13.47
Maximum	78.00	64.00
Mdn	2.00	5.50
Minimum	0.00	0.00
e^- (initial long-futures arbitrage position)		
N	2,297	151
M	6.15	18.25
SD	11.55	23.80
Maximum	79.00	84.00
Mdn	1.00	14.00
Minimum	0.00	0.00

Note. This table shows the length of the holding period for traders facing zero and member-level costs and employing an early-unwinding strategy.

increases to 5.71 points, in contrast to the profit of 3.95 points before unwinding. Out of 3,035 of the short-futures/options contracts, 2,558 (84%) could be successfully unwound. The average total profit from these short-futures/option contracts increases from 4.02 points to 5.50 points after unwinding. For the long-futures/options contracts, 70% could be successfully unwound, increasing the average total profit of the long-futures/option increases to 5.96 points (3.88 points before unwinding).

Table VIII shows the position for levels of transaction costs associated with members and at-the-money options. Once transactions costs are allowed for, it is apparent that profitable unwinding is problematic. For members, only 253 out of 2,492 trades (10%) could be successfully unwound.[22] Unwinding is especially difficult in a volatile market because the strategy requires the matching of the contracts with the same expiration and exercise price as those in the initial portfolio. Holding periods until positions are unwound are given in Table IX. Average holding

[22]For nonmembers, only 2 out of 114 trades (1.7%) could be successfully unwound.

TABLE X
Regression Test on the Factors Affecting the Magnitude of the Mispricing

	No Cost	*Member*
N	6,296	2,492
F	244.70**	163.97**
R^2	0.1893	0.2836
α (t value)	1.3259	−2.1734
	(7.64)**	(−7.39)**
β_1	0.5823	−0.3193
	(36.20)**	(−9.31)**
β_2	0.2844	−0.2927
	(2.00)*	(−1.50)
β_3	0.0091	−0.0155
	(3.04)**	(−2.99)**
β_4	−9.99	12.2502
	(−4.64)**	(4.81)**
β_5	0.1515	0.1969
	(1.11)	(0.82)
β_6	−0.1993	6.7866
	(−1.48)	(28.19)**

Note.

$$e = \alpha + \beta_1\psi + \beta_2\sigma + \beta_3 t + \beta_4 L + \beta_5 D_1 + \beta_6 D_2 + \varepsilon$$

e is the magnitude of the arbitrage profit in index points, ψ is the total spread cost, σ is an average of the volatility implied by the call and put options, t represents the remaining days to maturity, $L = |F - X|/X$ is the degree of moneyness (if $F > X$, then $D_1 = 1$; otherwise, $D_1 = 0$), and $D_2 = 0$ is the hedging strategy ($D_2 = 1$ is the short-futures strategy and $D_2 = 0$ is the long-futures strategy). When traders face no transaction cost, the size of the pricing error is affected by the size of the spread (β_1). The larger the spread is, the larger the pricing error is. Trading strategy, time to maturity, volatility, and the extent of the moneyness of the option are also important. For the member level of cost, volatility becomes insignificant (and changes sign), but the type of hedging strategy assumes importance.

*Statistically significant at 5% level.

**Statistically significant at 1% level.

periods are under 7 and 16 days for traders facing zero and member-level costs, respectively.

The results of the regression of the ex-post pricing error (e) against different variables are given in Table X. As we expect, when traders face no transaction cost, the size of the pricing error is affected by the size of the spread (β_1). The larger the spread is, the larger the pricing error is. The trading strategy, time to maturity, volatility, and extent of the moneyness of the option are also important. For the member level of cost, volatility becomes insignificant (and changes sign), but the type of hedging strategy assumes importance. Unfortunately, although there is considerable overlap in the variables that are important in both regressions, the change in sign of the major explanatory variables is puzzling.

CONCLUSIONS

Ex-post arbitrage profits for traders facing transaction costs are concentrated in at-the-money options. Opportunities are limited and generally are rapidly extinguished in less than 3 min. Profits are larger the greater the spread, volatility, and time to maturity are, but the average ex-post profit is very close to the ex-ante profit for lags of less than 3 min. Long-futures trades are marginally more profitable than short-futures strategies. Early unwinding may also be profitable, but for traders facing even low levels of transaction costs, the number of opportunities is small.

The use of a put–call–futures parity model has removed many of the problems identified in previous studies. The results suggest that arbitrage opportunities for traders facing transaction costs are small in number and confirm the efficiency of the market.

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