COMPARATIVE PRICING OF AMERICAN AND EUROPEAN INDEX OPTIONS: AN EMPIRICAL ANALYSIS

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The London International Financial Futures Exchange (LIFFE) appears to be unique in trading both European and American contracts on the same underlying stock index (the FTSE-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 data base of market bid–ask quotes for both American and European options are 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 is found for American options 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 study begins with a review of previous empirical research followed by the derivation of certain boundary conditions for the value

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of the early exercise right. The FTSE-100 index, the specification of the option contracts, and the data base used to test the boundary conditions are described. The tests and results are then presented. From these a trading rule is developed and tested. An investor order placement strategy is suggested.

PREVIOUS RESEARCH

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

Zivney (1991) undertook a novel boundary condition study that assumed 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 sampled closing prices of S&P 100 index options for each trading day of 1985. He found a mean value of the early exercise right greater than the theoretical values which Blomeyer and Johnson (1988) postulated for individual equity options, even though the value of early exercise should be lower for index options. He concluded that the market is efficient and that option pricing models "fail to capture all the nuances of the early exercise decision."

One of these nuances is described by French and Maberly (1992). They argue that, a priori, call options on the S&P 100 index ought not to be exercised since the dividend stream on the index so closely resembles a continuous dividend yield. In practice, more than 28% of such contracts are exercised early. This is attributed to a so-called "wild card" option–an interval of 15 minutes after the market close during which an option holder has the ability to choose to exercise or not. The arrival of price sensitive information during this interval does not affect the cash settlement available to holders of call options who choose to exercise that day, but does influence the opening value of the options if they are held until the following day. This wild card is a put option on the call option and French and Maberly find it to be a significant factor in pricing short-term options.

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 derivative instruments because 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.

BOUNDARY CONDITIONS FOR THE EARLY EXERCISE RIGHT

American Call Options

Merton (1973) established that early exercise of call options on stocks is rational only at the ex-dividend instant and then only if

$$S - X \geq S - \alpha D - Xe^{-r\tau} \tag{1}$$

where S is the level of the stock price (or index), X, the exercise price, αD, the immediate decline in price due to a dividend payment, r, the prevailing riskfree interest rate, and τ, the time to expiry. This study uses (1) to establish two boundary values, called τ^* and X^*. These are calculated at each ex-dividend event.

τ^* is the maximum interval between the ex-dividend instant and expiry which permits rational early exercise. It is derived by redefining (1) as an equation rather than an inequality, substituting τ^* for τ and solving for τ^* to give:

$$\tau^* = \frac{\ln\left[\dfrac{X - \alpha D}{X}\right]}{-r} \tag{2}$$

At each ex-dividend event during the life of the option, the prevailing values of X, αD, r, and τ are all readily observable. If $\tau > \tau^*$ for all ex-dividend events during the life of the option, early exercise is irrational and, hence, the value of the early exercise right is zero. In such cases, the option should have the same value as a European option with the same specifications.

The second boundary value is X^*, the maximum exercise price at each ex-dividend event for which early exercise may be rational. It is similarly derived by redefining (1) as an equation, substituting X^* for X and solving for X^* to give:

$$X^* = \frac{\alpha D}{1 - e^{-r\tau}} \tag{3}$$

Once again, the prevailing parameters in (3) 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.

Thus, the value of the early exercise right of an American call option on a stock or index is zero unless at some ex-dividend event during the life of the option:

i. $\tau < \tau^*$, and
ii. $X < X^*$.

These two conditions are necessary but not sufficient. Note that both τ^* and X^* are positive functions of αD. Hence, in the case of options on an index, whose dividend stream generally consists of frequent payouts with small values of αD, τ^*, and X^* will generally be small, implying that early exercise of these options will rarely be rational.

American Put Options

Merton (1973, theorem 4) established the *convexity* condition: given three options, O_1, O_2, and O_3, 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 $M(O_1)$, $M(O_2)$, and $M(O_3)$ will comply with the following inequality:

$$M(O_2) \leq \lambda M(O_1) + (1 - \lambda)M(O_3) \tag{4}$$

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 O_1, sell 1 option O_2, purchase $(1 - \lambda)$ option O_3]. If the butterfly can be established for a negative rather than a positive cost, (4) 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) will not necessarily apply to 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 against him of his short position which cannot be matched by the early exercise of the options he holds long. Thus, a compensating value for this must be factored into (4). As shown above, this is rarely a consideration in index call options, because of the nature of the dividend stream. In the case of index put options, early exercise may be rational at virtually any time, and so this requires modification of (4).

Consider the case of a butterfly consisting of European put options. As mentioned, (4) 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 O_2, the option sold short, is American rather than European. It will be exercised immediately and its value is thus X_2 rather than $X_2e^{-r\tau}$. Since (4) holds for an all-European butterfly, it follows that if a term is incorporated that reflects the difference between the American and European values of option O_2 in the extreme case of the index falling to zero on the day of transaction, a boundary condition applying to a mixed European–American–European put option butterfly results. This term is $X_2(1 - e^{-r\tau})$ giving a boundary condition of:

$$M(O_2) \leq \lambda M(O_1) + (1 - \lambda)M(O_3) - X_2(1 - e^{-r\tau}) \qquad (5)$$

In theory, (5) is robust; but, in practice, it is unrealistic. The catastrophic collapse of a major stock market index to zero would cause such turmoil to the global economic and financial systems that counterparty default risk could not be assumed away and standard boundary conditions would thus become inapplicable. Instead, a more realistic boundary that is capable of withstanding a major rather than a catastrophic one day collapse in the index is developed.

Assume that instead of falling to zero immediately after the transaction, the index falls to $0.75X_2$. The American option O_2 is exercised for proceeds $X_2 - S$; whereas, a European option of the same specification will have a minimum value of $(X_2 - S)e^{-r\tau}$. Thus, the maximum difference on exercise between the American and European values is $(X_2 - S) - (X_2 - S)e^{-r\tau}$. Since, by assumption, $S = 0.75X_2$, this simplifies to $0.25X_2(1 - e^{-r\tau})$. Incorporating this term in (4) gives a revised boundary condition of:

$$M(O_2) \leq \lambda M(O_1) + (1 - \lambda)M(O_3) - 0.25X_2(1 - e^{-r\tau}) \qquad (6)$$

How large a collapse (6) will withstand is an inverse function of how widely applicable one wishes it to be. If the application of the boundary condition excludes deep in the money American put options ($S < 0.9X_2$), then (6) will be capable of withstanding an immediate collapse in the market from $S \geq 0.9X_2$ to $S = 0.75X_2$, i.e. $\geq 16.67\%$.

THE FTSE-100 INDEX, INDEX OPTIONS, AND DATABASE

The FTSE-100 index

The FTSE-100 index was introduced in 1984 and has become the most widely quoted of the U.K. stock market indices. It was set at a base value of 1000 on December 31, 1983, and is recalculated every minute of the mandatory quote period (currently 8:30 AM to 4:30 PM). As the name implies, the index is based on the share prices of 100 leading companies: it uses an arithmetic average, weighted by market capitalization, unadjusted for dividends.

Given the importance of the dividend stream to early exercise decisions, it is worth outlining here the pattern of the dividend stream for the constituents of the FTSE-100 index. The majority of the constituents pay dividends twice yearly. Stocks are generally marked ex-dividend on the first day of an account period, which is normally two weeks long. The gross dividend yield on the index is of the order of 4%, which, with an index level of about 2200 points during the period sampled, implies a mean ex-dividend fall of about 3.6 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 are recorded.

FTSE Options Contracts

The American FTSE-100 index option contracts were introduced in May, 1984. Detailed specifications have changed over time, but the current specifications are as follows. The value of the contract is £10 per index point. Exercised options are settled in cash. Contracts are traded between 8:35 AM and 4:10 PM. Settlement price for options exercised early is the index level at 4:10 PM. Early exercise must be notified by 4:30 PM on the exercise day. Thus, the wild card option described by French and Maberly lasts for 20 minutes. At expiry, the notification deadline is extended to 6 PM. Contracts expire on the third Friday of the delivery month. Settlement at expiry is based on the arithmetic mean of the index level quotations between 10:10 AM and 10:30 AM on expiry day, after elimination of the three highest and three lowest quotes. Expiry months are June and December plus additional months to ensure that the nearest four calendar months are always trading. Exercise prices are generally set at intervals of 50 points. A wide range of exercise prices is available, typically eight in the money and eight out of the money.

The European FTSE-100 index option contracts were introduced in February, 1990, trading in the same pit as the American contracts. The basic terms are similar to those for the American contract. Expiry months are March, June, September, and December plus additional months to ensure that the nearest three months are always trading. A similarly wide range of exercise prices is available, but, to avoid confusion in the trading pit, these exercise prices are offset from the exercise prices of the American contracts by 25 points.

Data Base

The data base consists of a second-by-second record of all bid–ask quotations for American and European options on the FTSE-index for 96 consecutive trading days from July 1, 1992 until November 12, 1992. These quotes are generated whenever a participant in the market asks for a price from the crowd in the trading pit. They are matched with a minute-by-minute record of the FTSE-100 index. These data are supplied by LIFFE.

Additional information gathered includes:

- the size of the ex-dividend fall, expressed in index points, for each ex-dividend day from the first day of observation until the expiry of the last options series observed, February 1993. This is obtained from the London Stock Exchange.
- the 3-month LIBOR rate for each of the observation and relevant ex-dividend days. This is obtained from Datastream.

This sample is refined to eliminate expiry months which do not contain both American and European options series. The refined database contains 154,402 bid–ask quotations broken down as shown in Table I.

TABLE I
Breakdown of Sample

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

ANALYSIS

Specification of the Tests

As shown above, the value of the early exercise right on American call options on a stock index is zero unless at some ex-dividend event during the life of the option, two boundary conditions are met. These conditions are met in 9574 cases (16.53%) from 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.

A test for a zero value of the early exercise right for these options is performed by the application of (4). Butterfly spreads are constructed using the observations of American call options as O_2 and observations of European options as O_1 and O_3. Since (4) is applicable to portfolios of European options and since the American options tested have no early exercise value, (4) is applicable to such portfolios. If the butterfly can be established with a cash inflow, (4) is violated.

In the case of American put options, (6) is used in a similar way with an American put option as O_2 and European put options as O_1 and O_3. The sample is filtered to eliminate all observations of American put options in which $S < 0.9X_2$, thus rendering (6) capable of withstanding a fall in the market of at least 16.67%. Such deep in-the-money options are infrequently traded and hence infrequently quoted, so this filtering removes only 2636 observations (4.24%). If the butterfly can be established with a cash inflow exceeding $0.25X_2(1 - e^{-r\tau})$, (6) is violated.

The Search Procedure

To test 48,336 observations of American call options and 59,550 observations of American put options, each of these bid–ask quotes is used as a potential option O_2. Noting the index level at the time of this quote, the data base is searched for the next quotes on the same day of European options with the same expiry and with exercise prices 25 points on either side of option O_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 induced by an index change during this interval. This is minimized 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 time of the relevant European quotes does not meet this criterion, the observation is discarded.

Even the latitude of ± 2 index points over the duration of the observation may induce a small bias to the results, which is countered by presenting a second set of results for each test. In these adjusted results, the observed prices of the options held long is 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 II and III. 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, the adjustment is made for any bias caused by index movements during the observation as described above.

TABLE II

Tests of American Call Options Against (4) (American Calls Sold Short, European Calls Held Long)

Sample	n	*Violations*	%	*Mean Size of Violation*	*% of O_2 Price*	*Maximum Violation*	*Mean Duration of Observation*
AAA	11,735	3196	27.23%	3.18	7.04%	44.00	109'36"
BBB	11,735	4838	41.23%	3.02	10.52%	45.00	105'12"
ABA	11,735	517	4.41%	4.34	6.35%	39.00	134'03"
After adjustment for index movements during observation							
AAA	11,735	2880	24.54%	3.11	6.49%	44.00	107'02"
BBB	11,735	4408	37.56%	2.91	9.42%	44.00	101'39"
ABA	11,735	439	3.74%	4.63	6.48%	39.00	130'10"

TABLE III
Tests of American Put Options Against (6) (American Puts Sold Short, European Puts Held Long)

Sample	n	*Violations*	%	*Mean Size of Violation*	*% of O_2 Price*	*Maximum Violation*	*Mean Duration of Observation*
AAA	12,964	2593	20.00%	5.60	6.08%	41.13	97'57"
BBB	12,964	3642	28.09%	4.72	7.02%	41.99	96'39"
ABA	12,964	1020	7.87%	6.19	4.97%	36.20	84'40"
		After adjustment for index movements during observation					
AAA	12,964	2386	18.40%	5.72	5.93%	40.93	95'36"
BBB	12,964	3259	25.14%	4.88	6.67%	41.99	93'07"
ABA	12,964	952	7.34%	6.34	5.27%	35.40	80'58"

Tables II and III show a notable incidence of overpricing of the early exercise right. 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 are also in line with French and Maberly (1992) who identify a "wild card" option not incorporated in standard option pricing models. As shown above, the wild card option in the FTSE-100 index examined here has a life of 20 minutes.

Nevertheless, it may not be prudent to interpret the results of Tables II and III in this way. First, all three studies claim to identify flaws in standard option pricing models, but the results of this study are model-independent. Second, the effect of information arrival during the 20-minute wild card period can be measured on the London market, since the index is updated on a minute-by-minute basis during that period. This effect is found to be very small. In the data base analyzed in this survey, the mean change in the index during this 20-minute period is -0.545 index points (-0.02%), with a standard deviation of 1.99 index points (0.08%). Hence, the value of the "wild card" option will also be small.

Another convexity test is performed in which (4) is applied to portfolios where options O_1 and O_3 are American and option O_2 European. If the violations identified in Tables II and III are evidence of systematic overpricing of the early exercise right, only few or no violations should be found in the reciprocal cases where the options held long are American and those sold short European.

TABLE IV

Tests of European Call Options Against (4) (European Calls Sold Short, American Calls Held Long)

Sample	n	*Violations*	%	*Mean Size of Violation*	*% of O_2 Price*	*Maximum Violation*	*Mean Duration of Observation*
AAA	5418	1543	28.48%	3.83	9.87%	46.5	34′52″
BBB	5418	1147	21.17%	4.10	9.61%	46.0	37′41″
ABA	5418	174	3.21%	11.26	12.35%	41.5	31′37″
After adjustment for index movements during observation							
AAA	5418	1456	26.87%	3.82	9.58%	46.4	31′59″
BBB	5418	1075	19.84%	4.11	9.12%	46.0	34′09″
ABA	5418	168	3.10%	11.31	12.30%	41.4	31′03″

Therefore, all the observations of European bid–ask quotes are tested against (4) by constructing American–European–American butterflies using the same search criteria as in the previous tests. The results are shown in Tables IV and V. Overpricing of European options is found with about the same frequency as overpricing of American options.

Thus, it is concluded that the violations observed in Tables II and III 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 American options only.

TABLE V

Tests of European Put Options Against (4) (European Puts Sold Short, American Puts Held Long)

Sample	n	*Violations*	%	*Mean Size of Violation*	*% of O_2 Price*	*Maximum Violation*	*Mean Duration of Observation*
AAA	6420	1121	17.46%	3.09	12.68%	39	46′26″
BBB	6420	641	9.98%	3.36	14.97%	39	58′03″
ABA	6420	108	1.68%	7.83	11.97%	34	59′30″
After adjustment for index movements during observation							
AAA	6420	1059	16.50%	2.80	11.13%	38.05	43′42″
BBB	6420	602	9.38%	3.35	13.61%	38.05	53′08″
ABA	6420	105	1.64%	7.79	10.86%	33.05	56′53″

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 tests 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 he cannot know at the start of that interval that subsequently arbitrage opportunities will occur. Since a trader is unable to trade ex post, an ex ante trading rule is developed which is applied to the data base 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. Assume 6 contracts of O_2 are sold short and 3 contracts each of options O_1 and O_3 are held long. Thus, 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.

This simulation is hindered by market illiquidity. In practice, the hypothetical trader can ask for a quote on any options series in which he is interested at any time. This simulation is restricted to quotes observed in the data base. The search criteria that there exist quotes for the required options series within a time interval during which the index has moved by no more than ± 2 index points are applied to the 1480 violations to be tested. The search criteria are met in only 243 cases. The results are presented in Table VI.

Table VI indicates that the trading rule would not be profitable. The mean cost of establishing the butterfly spreads is positive for all except the American puts, but the objective is to establish these spreads at a negative cost. The trading rule looks more effective for the American puts, but the constraints of the market illiquidity described above mean that there are only a very limited number of observations in the simulation.

TABLE VI
Results of Simulated Arbitrage Trades

Sample	n	*Mean Cost*	*% of O_2 Price*	*Violations*	*% of Sample*	*Mean Violation*	*% of O_2 Price*	*Maximum Violation*	*Mean Time*
American calls	58	1.38	2.18%	12	20.69%	10.04	12.78%	17.00	53'19"
American puts	118	−3.44	−7.15%	50	42.37%	5.96	4.57%	15.33	44'12"
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"

Investor Order Placement Strategy

As noted above, there is more liquidity in the American options than in the European. Table I 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 is 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) found a similar lack of interest in European foreign currency options.

Yet in the case of index call options, this investor preference for American rather than European options is unjustified. Early exercise is irrational for the great majority of American call options traded. Thus, the investor seeking to open a call option position should be indifferent between the style of option. He 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 the series he is interested in (thus generating an observation for the data base) and, if the price meets his client's requirements, a trade is struck. It would seem that brokers should call for *two* quotes: one American and the other a nearby European series. The broker would then trade whichever series appears to be more favorably priced. The difference in the frequency of quotes observed in the database for the two styles of options shows that this is not happening at present.

If such a strategy were adopted, one would expect to see a greater frequency of quotes for the European options, an increase in the volume of European options traded, and an eventual elimination of the relative mispricing. 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.

CONCLUSION

This study derives boundary conditions for the value of the early exercise right and tests these conditions in a market trading both American and European options on the same underlying index. These conditions are applied in convexity tests where 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 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 introduction of European options. An earlier pilot study[1] observing the market in the six months immediately following introduction of the European options, found similar results.

Investors show a marked preference for American options, which is irrational, at least in the case of most call options. An order placement strategy for investors opening a position is suggested that calls for obtaining quotes on two options series, an American one and a nearby European one. They would then trade in the series which appeared to be more favorably priced. It is hypothesized that such a strategy would lead to an increase in the volume of European options traded and would eradicate the comparative mispricing observed in this article. This hypothesis awaits testing.

APPENDIX 1: FILTER OF AMERICAN CALL OPTIONS FOR WHICH EARLY EXERCISE MAY BE RATIONAL

This article derives two necessary but not sufficient conditions for early exercise of call options to be rational. In this appendix, these conditions

[1] Details available from the author.

are applied to each ex-dividend event relevant to the study and those options series which meet the two conditions are filtered out. Early exercise of those remaining will be irrational, and, therefore, they can be valued as European options.

Table VII shows that November options with an exercise price of less than 2277, together with all December and all February options, meet both conditions. These account for 9574 observations, which are removed from the data base, to leave 48,336 observations of American call options to be tested.

The filter assumes certain foreknowledge. For example, the November options started trading in August 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 Table VII 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.

TABLE VII

Application of Boundary Value Tests to American Call Option Sample

Ex-Dividend Instant	αD	r	*Minimum X*	*Minimum* τ	τ^*	X^*	*Series Passing Both Tests*
10 Jul 92	2.21	0.1000	2050	7	4	1153	None
14 Jul 92	5.28	0.1019	2050	28	9	678	None
7 Aug 92	7.13	0.1013	2050	14	13	1840	None
21 Aug 92	1.34	0.1025	2050	28	2	171	None
4 Sep 92	2.09	0.1019	2050	14	4	536	None
18 Sep 92	8.34	0.1050	2050	28	14	1040	None
2 Oct 92	1.84	0.0894	2050	14	4	538	None
16 Oct 92	2.79	0.0788	2050	35	6	371	None
30 Oct 92	1.20	0.0775	2050	21	3	270	None
13 Nov 92	3.00	0.0688	2050	7	8	2277	November expiries with $X \leq 2277$
27 Nov 92	2.12	0.0719	2050	21	5	514	None
11 Dec 92	5.25	0.0706	2050	7	13	3879	All December expiries
31 Dec 92	2.43	0.0688	2050	15	6	861	None
15 Jan 92	0.96	0.0688	2050	35	2	146	None
29 Jan 92	0.08	0.0625	2050	21	0	22	None
12 Feb 92	6.41	0.0619	2050	7	18	5405	All February expiries

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