THE INTRADAY DISTRIBUTION OF VOLATILITY AND THE VALUE OF WILDCARD OPTIONS

PAUL DAWSON

This study investigates the value of the wildcard option embedded in the American FT-SE 100 index (SEI) options. Model-based studies of S&P 100 index options show the embedded wildcard option to have significant value. By contrast, nonparametric tests on SEI options indicate that the wildcard has very little value. The contrasting results arise because U.S. studies observe a high level of volatility during the 15-minute wildcard period, whereas the 21-minute wildcard period in London is relatively quiet. The present study highlights the sensitivity of the wildcard value to the intraday distribution of volatility and indicates the difficulty in estimating the wildcard period volatility, since it is itself volatile. © 2000 John Wiley & Sons, Inc. Jrl Fut Mark 20:307–320, 2000

INTRODUCTION

A wildcard option arises whenever an investor enjoys an interval following the determination of the day's settlement price during which to decide whether or not to deliver (futures) or exercise (cash-settled options). In-

The author is grateful to Gordon Gemmill and an anonymous referee for helpful comments on earlier drafts and to LIFFE and seven undergraduate students for assistance in data collection. Any remaining errors are the author's own. Tel: +44 171 477 8972; Fax: +44 171 477 8885; e-mail: pedawson@city.ac.uk.

■ *Paul Dawson is in the Department of Investment Risk Management and Insurance at the City University Business School in London, United Kingdom.*

The Journal of Futures Markets, Vol. 20, No. 4, 307–320 (2000)

formation arriving during this period may affect the value of the unexercised option or undelivered future, but will not alter the exercise or delivery value. Hence the wildcard feature establishes a minimum value for the asset until the end of the wildcard period, regardless of the information set arriving. It thus has the characteristics of a short-term put option.

The wildcard option is familiar to investors short of the T-Bond futures contract. During the delivery month, they may make delivery at anytime up to 20:00 (Chicago time) but receive the value determined at 14:00. Analysis of this option can be found as far back as Gay and Manaster (1986), Kane and Marcus (1986), and Hegde (1988). More recently, attention has been given to the wildcard option embedded in another liquid derivative security—American style stock index options. Fleming and Whaley (1994) estimate the daily trading value of the wildcard feature embedded in the S&P 100 index options to be of the order of $5 million. Option writers who ignore this feature effectively give away a valuable free option embedded in the option they sell.

This study uses a nonparametric approach to analyze the wildcard option embedded in FT-SE 100 index options. A simple boundary condition establishes the maximum incidence of exercise of the wildcard option. It is found that the wildcard option may be rationally exercised on rare occasions only and is thus of insignificant value.

The contribution of this study is threefold. First, there has been no previous nonparametric study of wildcard option exercise. As Diz and Finucane (1994, p. 770) point out "there is some disagreement in the literature concerning the importance of the wild card option." Boundary condition tests, being model-independent, avoid the principal areas of contention. Second, empirical analysis is extended to a market different from the S&P 100 index options that have been the focus of previous research. This extension to a different market provides evidence that the value of the wildcard option is not universally significant and is dependent on the intraday distribution of volatility. Third, analysis of this different market highlights the sensitivity of the Fleming and Whaley (1994) wildcard option pricing model to the *wildcard period volatility adjustment factor* (i.e., to the assumed relative volatility during the wildcard period), and the problems of estimating this factor are considered.

This paper is organized as follows: first, the literature is reviewed; next, there is a description of the market studied, the data analyzed, and the methodology employed. The results are then presented and the contrasting values of this wildcard in the United States and the United King-

dom are discussed, reconciling the current results with those of the U.S. research. The final section gives the conclusions.

REVIEW OF LITERATURE

Published research is confined to the S&P 100 index (OEX) options. The wildcard interval on OEX options now lasts for 20 minutes, from 15:00 until 15:20 Central Time.[1] During this period, the New York Stock Exchange is not trading, so the S&P 500 index futures contract, which is traded during the interval, is used as a proxy for the underlying asset.

French and Maberly (1992) start from the observation that the number of OEX call options exercised early cannot explained by dividend payments alone. They conclude that the wildcard option is a statistically significant cause of early exercise.

Diz and Finucane (1994) also investigate the incidence of wildcard execution of OEX options, in the context of a wider examination of rational early exercise of both put and call options. They use a binomial pricing model to identify the incidence of execution which is made rational by the existence of the wildcard option. Their results also show that the wildcard appears to have significant influence on early exercise practice on these options.

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

Fleming and Whaley (1994) develop a straightforward and insightful adaptation of the binomial model to value wildcard options. In essence, their model calls for the timesteps on the binomial tree to coincide with the start of the wildcard interval for each day, and for the addition at each node of the value of that day's individual wildcard option, which can itself be valued using a straightforward adaptation of Black-Scholes. This model will be used later to reconcile the findings of the present study with those of earlier studies.

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

THE MARKET, DATABASE, AND METHODOLOGY

This paper studies the American FT-SE 100 index options traded on LIFFE, known as SEI options. The options are traded in an open outcry pit. Market trading hours for the options are 08:35 to 16:10. The options contract is quoted in index points and valued at £10 per point, with a tick size of ½ point. Typical bid–ask spreads are 2 points for at and out of the money options rising to 5 points for deep in the money options. The proceeds of exercise are determined by the value of the index at 16:10, rounded to the nearest half point, and the option holder has until 16:31 to communicate an early exercise decision to the clearing house. The wildcard interval thus lasts 21 minutes.

During this interval, the underlying spot market is still open. Studies of stock index derivatives, e.g., Stoll and Whaley (1990), frequently comment that an index derived from the last transaction's prices will suffer from a stale price problem: if a stock has not traded since the arrival of price-sensitive information, then its contribution to the index value will reflect obsolete information. For the market and period presently studied, this problem is essentially absent. The spot market was a quote-driven market with all registered marketmakers required to maintain binding bid and ask quotes throughout the mandatory quote period—08:30 to 16:30. The spot index was calculated from the midpoints of the inside spread of these quotes. Since these quotes were binding in institutional size (greater than $1 million), the marketmakers have a powerful financial motive to update their quotations immediately to reflect information arrival.[2]

The database used in this survey comprises closing observations of all put and call options series that are in the money at 16:10 for a 780 trading-day period from 4 January 1993 to 31 January 1996. The sample size is 33,045 (19,733 calls and 13,312 puts). Each observation comprises:

1. Trading date
2. Option specification (strike price, expiry, and put or call classification)
3. Open interest at the start of each day
4. Trading volume
5. 16:10 bid price

[2]Since 20 October 1997, the FT-SE 100 index has been calculated from last transactions prices, thus introducing potential for the stale price problem and, importantly, the potential for improper manipulation of closing prices, which may increase the significance of the wildcard option.

TABLE I

Sample Observation From Database Analyzed

Date	*Expiry*	*Strike price*	*Class*	*Open interest at start of day*	*Day's trading volume*
14-Dec-95	Dec-95	3650	C	4,390	666
Open interest at start of next day	*Instrument settlement price*	*Exercise proceeds*	*16:10 bid price*	*08:30 spot index level*	*16:10 spot index level*
4,216	3674.5	24.5	25.0	3673.7	3674.5
16:30 spot index level	*Wildcard period change in index level*	*Implied 16:30 option bid price*	*Days to expiry*	*Moneyness*	
3671.6	−2.9	22.0	1	0.67	

6. The daily index settlement value, used to determine the exercise proceeds
7. Spot index levels at 08:30, 16:10, and 16:30

The observations embrace a total of 960 different options series (529 calls and 431 puts) with strike prices ranging from 2300 to 4100 and expiries from January 1993 through December 1996. All data was provided by LIFFE except for the spot index levels, which were extracted from the *Financial Times*. A sample observation is given in Table I.

Exercise of a cash-settled option is entirely analogous to a sale. The option holder is relieved of the option position and receives cash in exchange. Thus an option holder who wishes to close a position will simply choose between exercise and market sale through the comparison of the respective receipts. For very short expiry and/or deep in the money options, exercise may be an economical way of avoiding the bid–ask spread; see Diz and Finucane (1994, p. 767). This paper analyzes the circumstances in which the existence of the wildcard option may change rational investor behavior. This can illustrated with the example in Table I.

Consider an investor on 14 December 1995 holding Dec 3650 calls. The 16:10 spot index was 3674.5; hence the proceeds of exercise were 24.5. The market bid price at 16:10 was 25, so exercise at this time would be irrational. However, by the end of the wildcard period, the index had fallen 2.9 points to 3671.6. Assuming an option delta of 1, the implied 16:30 bid value of the options is 22 (allowing for the tick size of ½ point). At this stage, it would be rational for the investor to exercise, since the proceeds of exercise exceed the revised bid value. Thus the existence of the wildcard option offers call option holders some protection against an

index fall during the wildcard interval. For put option holders, the wildcard option provides an equivalent protection against an index rise during the wildcard interval.

The assumption of an limiting option delta of 1 (or -1 for puts) is justifiable. The wildcard option will be exercised only if market conditions are such that the option is close to being rationally exercised. Since rationally exercised options have a delta of 1 (-1 for puts) the assumption is reasonable and serves the purpose of the boundary condition test, namely to find an upper bound to the impact of the wildcard option.

Thus, rational exercise of the wildcard option requires that the change in the underlying index during the wildcard interval be sufficient to reduce the implied bid price of the option to less than the proceeds of exercise.

Stated formally, with S the value of the spot index at 16:10, P the market bid price of the option at 16:10, X the strike price of the option, and ΔS the change in the spot index value during the wildcard interval, exercise of the wildcard option is rational only if
For calls:

$$P + \Delta S < S - X \tag{1}$$

For puts:

$$P - \Delta S < X - S \tag{2}$$

The methodology adopted in the nonparametric study is to identify from the sample all observations which comply with these conditions and then to analyze the characteristics of the options in the identified sample. These characteristics include

- Daily trading volume.
- The open interest; data on the open interest at the start of the wildcard interval are not available, but a maximum figure can be derived from adding the day's trading volume to the open interest at the start of the day.
- The maximum extent to which the wildcard option has been exercised, calculated as the maximum open interest at the start of the wildcard interval less the open interest at the start of the following day.
- The mean number of days to expiry.
- The degree of moneyness of the options, defined as $100(S \div X - 1)$ for calls and $100(1 - S \div X)$ for puts.

TABLE II

Observations from database sample which comply with conditions (1) or (2)

	Calls	*Puts*	*Total*
Sample size	19,733	13,312	33,045
Compliance with conditions (1) or (2)	726	905	1,631
	3.68%	6.80%	4.94%
Mean daily trading volume of all SEI options	5,666	6,469	12,135
Mean daily trading volume of options series complying with conditions (1) or (2)	43.8	52.9	96.7
	0.77%	0.82%	0.80%
Mean daily open interest for all SEI options	67,460	95,786	163,246
Potential wildcard exercise volume = mean open interest of options series complying with conditions (1) or (2) at start of day + day's trading volume	495	407	901
	0.73%	0.42%	0.55%
Mean daily exercise volume of options series complying with conditions (1) or (2)	88	97	186
% of potential wildcard exercise volume	17.78%	23.83%	20.64%
Mean moneyness of options complying with conditions (1) or (2)	11.8	6.0	8.6
Mean number of days to expiry of options complying with conditions (1) or (2)	24.8	35.2	30.5

RESULTS

Table II shows the number of observations which comply with conditions (1) and (2). Table II shows that only a small number of options series from the database comply with the rational exercise condition. The total of 1,631 instances of compliance over a 780 day period implies that exercise of the wildcard option would be rational for only 2.1 option series on a typical day. Given that the typical day has 42 in the money option series open, this preliminary count indicates that the wildcard option is of little significance in the London market.

Nevertheless, the significance of the feature should not be dismissed without consideration of the open interest. Table II shows that the mean daily open interest of all SEI options exceeds 163,000, but the mean daily open interest of options complying with conditions (1) or (2) is less than 1,000, or barely 0.5% of this figure.

The open interest data can be analyzed further to see the extent to which option holders are choosing to exercise the wildcard option. The maximum open interest figure at 16:10 is compared with the open interest figure at the start of the following day. The difference indicates the maximum number of contracts exercised. It is seen that fewer than 200 con-

tracts complying with the rational wildcard exercise condition are actually exercised each day. This figure is barely 20% of the number of contracts that could be rationally exercised.

This final point does not itself imply irrational behavior. Holders of options that meet the rational wildcard exercise condition hold a highly geared position in the underlying asset. If the holders maintain a view on the direction the market will subsequently take, they may rationally decide to hold this highly geared position rather than close through exercise, even if the exercise proceeds exceed the implied market bid price for the options.

The extent of this gearing can be found by analysis of the moneyness and time to maturity of the options meeting the rational wildcard exercise condition. It can be seen that these options are deep in the money. The mean values in Table I for moneyness indicate that the call options are almost 12% in the money, and the put options about 6%. With a mean index level of about 3000 during the sample period, this implies that the identified call options are some 360 points in the money and the put options some 180 points in the money. Higher gearing could be obtained by exercise and the purchase of options with lower moneyness values, but this would incur transactions costs. Hence, the options holder might rationally choose to maintain the position in the deep in the money options, since Table II shows that they have approximately one month to move even further into money.

These nonparametric tests have thus shown:

- The embedded wildcard option is rationally exercised on only relatively few occasions.
- These occasions will generally arise only when the option is deep in the money.
- The open interest in such options is small.
- Hence it can be concluded that the wildcard option embedded in SEI options is negligible significance.

WILDCARD PERIOD VOLATILITY

The results shown in the previous section contrast markedly with the results found in U.S. studies, which show the OEX wildcard option to have significant value and for wildcard option exercise to be undertaken frequently. Like any other option, the value of the wildcard option depends on its volatility characteristics and insight can be obtained from analysis of the intraday distribution of volatility.

First it should be noted that in the United Kingdom, this volatility is measured by the performance of the spot index, which is the actual asset under option; whereas the U.S. studies use the volatility of the futures contract as a proxy, since the spot index is not observable during the U.S. wildcard interval. This may be significant. Numerous studies[3] show stock index futures markets to be more volatile than the underlying spot index, and the absence of access to the cash market during the wildcard interval means that the futures price is not constrained by cash to futures arbitrage forces so its volatility during this period may be increased still further.

Next, in London, there tends to be little price-sensitive information released during the wildcard interval. U.K. company announcements are generally made just prior to the opening of the London market or, in the case of companies also listed on the NYSE, just prior to the opening of that market (14:30 U.K. time). Official statistics are generally released at 09:00 and interest rate changes announced at 12:00. One rare example of a significant price-sensitive information release during the wildcard interval occurred at 16:26 on 15 May 1991, when Hanson announced the acquisition of a significant stake in ICI, widely expected to be the prelude to a hostile bid: this triggered a stock market recovery, see Hanson (1991).

In contrast, it appears that U.S. companies frequently release information (especially profit warnings) immediately after NYSE closure and thus during the U.S. wildcard interval. Catan (1999, p. 4), in discussing the New York Stock Exchange, states "Important company announcements and initial public offerings are normally made after the markets have ended for the day," and presents this as an argument for the lengthening of the stock exchange trading hours.[4]

For the period sampled in the present study, the mean return on the FT-SE 100 index during the wildcard interval was 0.02%, the maximum and minimum being 0.35% and −0.35%, respectively, with an interquartile range of −0.02% to 0.05%. The standard deviation was 0.00065. The significance of this for the value of the wildcard can be evaluated using the Fleming and Whaley (1994) wildcard-inclusive option pricing model.

Fleming and Whaley (henceforth FW), incorporate a *wildcard period volatility adjustment factor* (v). This is an adjustment of the annualized volatility used in wildcard-exclusive option pricing.

[3]See Board and Sutcliffe (1995) for a review.

[4]For example, Compaq announced a major profits warning after market closure on Friday 9 April 1999; see Kehoe (1999).

The intraday distribution of volatility and the value of wildcard options

TABLE III

Volatility ratios observed for the FT-SE 100 index and S&P 500 index futures contracts. The ratio is the volatility observed during the wildcard interval compared with the volatility observed in other time periods, adjusted to a unit time basis

	FT-SE 100 index				*S&P 500 index futures*			
	Full sample (1993–1996)	*1993*	*1994*	*1995*	*Full sample (1982–1991)*	*1991*	*Max*	*Min*
Trading day	0.380	0.427	0.307	0.454	0.915	0.789	1.147	0.636
Overnight	1.071	1.378	0.865	1.165	3.691	2.892	5.033	2.892
Close to close	0.627	0.700	0.523	0.714	1.596	1.375	1.930	1.149

Two extremes are considered in FW. At the lower bound, the volatility observed during the wildcard interval is assumed to be the same (on a unit time basis) as the close to close volatility. In such a case, $\nu = 1$. At the other extreme, it is assumed that all the volatility occurs within the trading day, and that the volatility in the wildcard interval is the same as that observed within the trading day, again on a unit time basis. Since the length of the trading day of the S&P 500 index futures contract, which FW use as the underlying asset in their empirical work, is 6¾ hours, this upper extreme value for ν is $(24 \div 6\frac{3}{4})^{1/2}$ or approximately 1.9.

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

$$\textit{Volatility ratio} = \sqrt{\frac{\sigma_w^2 \div 0.25}{\sigma_i^2 \div \text{hours}}} \tag{3}$$

where σ_w^2 is the variance during the wildcard period (divided by 0.25 because the length of the wildcard interval for the period they survey was ¼ hour), and σ_i^2 and $hours_i$ the variance and length of time in hours of the ith interval (i.e., trading day, overnight, or close to close).

FW present a detailed analysis of volatility ratios from a 10-year history of the S&P 500 index futures contract. A similar analysis is now undertaken for the FT-SE 100 index market over the 3-year period of the present study and the comparative results presented in Table III. This presents the U.K. data for the full sample and the three individual calendar years and compares them with the values found by FW for:

1. The full sample
2. The first 61 trading days of 1991, being the closest period they have to the period sampled in the present study
3. The maximum and minimum values recorded for any individual calendar year.

Table III shows not only that the intraday distribution of volatility in the U.K. is significantly different from that in the United States, but also (and importantly) that this distribution is itself volatile. Comparing the respective figures for the full samples, it can be seen that, on a unit time basis, the U.S. market is approximately 90% as volatile during the wildcard interval as during the trading day (0.915), whereas in the United Kingdom the figure is only 38% (0.380). The U.S. market is more than three times as volatile during the wildcard interval as during the overnight close (3.691), whereas the U.K. market has approximately the same volatility in these two periods (1.071).

Finally, and of greatest significance for the present study, the volatility observed during the wildcard interval in the United States is about 60% greater than the average of the entire calendar day (1.596), whereas in the United Kingdom, the wildcard interval volatility is 37% *lower* than the average of the calendar day (0.627).

In this lies the reconciliation between the insignificance of the SEI wildcard option found in the analysis just shown and the significance of the OEX wildcard option found in previous research. The value of the wildcard option is highly sensitive to the wildcard period volatility, and this is found to be very low in the United Kingdom.

Furthermore, Table III highlights a difficulty in the application of FW: namely, the estimation of the parameter v. In the U.S. market, the volatility of this parameter makes the use of historical analysis unreliable. As with conventional historical volatility estimates, different sampling periods generate quite different values and none of these may be a reliable predictor of the volatility to be expected over the forthcoming life of the option under analysis. For the United Kingdom, however, the low observed values of v give the wildcard option insignificant value, as shown next.

The incremental value of the wildcard option on the FT-SE 100 index can be determined by the difference between the FW price (wildcard inclusive) and an otherwise identical binomial model price (wildcard exclusive). Table IV shows the incremental value of the wildcard option for different values of v with parameter values typical of the database analyzed in this paper: $S = X = 3000$, $r = 0.1$, $t = 20 - 60$ days and $\sigma =$

TABLE IV

Incremental value (in index points) of wildcard option with $S = X = 3000$, $r = 0.1$, and $\sigma = 0.15$. The incremental value represents the difference between an option valued using FW and an otherwise identical option valued with the binomial option pricing model

t (days)	*v = 0.63*	*v = 1.00*	*v = 1.60*	*v = 1.73*	*v = 1.90*
20	0.28	0.69	1.46	1.64	1.89
30	0.30	0.73	1.57	1.78	2.05
40	0.31	0.76	1.66	1.87	2.16
50	0.32	0.79	1.72	1.94	2.25
60	0.33	0.82	1.78	2.01	2.32

TABLE V

Incremental value (in index points) of wildcard options with $S = 3000$, $r = 0.1$, $\sigma = 0.15$ and $v = 0.63$. The incremental value represents the difference between an option valued using FW and an otherwise identical option valued with the binomial option pricing model

t (days)	*X = 2800*	*X = 2900*	*X = 3000*	*X = 3100*	*X = 3200*
20	0.55	0.46	0.28	0.06	0.01
30	0.54	0.45	0.30	0.10	0.02
40	0.53	0.44	0.31	0.13	0.05
50	0.53	0.44	0.32	0.15	0.07
60	0.52	0.44	0.33	0.17	0.08

0.15 . The values of v chosen are 0.63 (mean value found in the present study), 1 (implied lower bound in FW), 1.6 (mean OEX value found in FW), 1.73 ($= (24 \div 8)^{1/2}$, the upper bound implied in FW for a market open for 8 hours) and 1.9 ($=(24 \div 6\frac{1}{2})^{1/2}$, the upper bound implied in FW for a market open for 6½ hours). Table V shows this value for different strike prices and maturities using $v = 0.63$.

The sensitivity to the value of v is clearly shown in Table IV. With $v = 0.63$, the incremental value of the wildcard option is about 0.3 index points—significantly less than one tick, while the bid–ask spread for such options is typically 2 points, or 4 ticks. However, with values typically observed in the U.S. market, the incremental value of the wildcard option is some five times as large, 1.5 index points, or 3 ticks.

The nonparametric tests already described show exercise of the wildcard option generally to be rational only for deep in the money SEI op-

tions. Table V shows that the wildcard value embedded even in such options is of the order of 0.5 index point, or 1 tick. Since the bid–ask spread for deep in the money options is typically 5 index points (10 ticks), it can be seen that the incremental value of the wildcard option is dominated by the microstructure of this particular market.

This therefore reconciles the insignificance of the wildcard option found in the present study of SEI options with the significance found in studies of OEX options. The SEI wildcard option value would be significant if the wildcard interval had volatility characteristics similar to those observed in the United States. FW value the wildcard feature in a typical OEX option (30 days, at the money) to be about $20. For SEI options, the equivalent value is £3 ($5). However, with values of v similar to those seen in the United States, the same SEI wildcard feature would be valued at about £16, or $25.

CONCLUSION

Stock index options are cash settled to avoid the frictions involved delivery of a basket of stocks. However, the cash settlement necessitates the embedding of a wildcard option, which creates a different friction. This friction serves little purpose in the principal economic function of index options, and it is thus desirable to minimize its impact. The present study demonstrates the dependence of the value of the wildcard option on the intraday distribution of volatility. The friction can be reduced to negligible levels if exchanges select a wildcard interval that is characterized by relatively low volatility. In the United Kingdom, whether by accident or design, this has been achieved. Other exchanges might choose to consider this point in the design of their index options products.

BIBLIOGRAPHY

Board, J., & Sutcliffe, C. (1995). The relative volatility of the markets in equities and index futures. Journal of Business Finance and Accounting, 22, 201–221.

Catan, T. (1999). Future nearer for New York night traders. Financial Times, 4, 4.

Diz, F., & Finucane, T. J. (1994). The rationality of early exercise decisions: evidence from the S&P 100 index options market. Review of Financial Studies, 6, 765–797.

Fleming, J., & Whaley, R. E. (1994). The value of wildcard options. Journal of Finance, 49, 215–236.

French, D. W., & Maberly, E. D. (1992). Early exercise of American index options. Journal of Financial Research, XV, 127–136.

Gay, G. D, & Manaster, S. (1986). Implicit delivery options and optimal delivery strategies for financial futures contracts. Journal of Financial Economics, 16, 41–72.

Hanson news helps equities to steady. (1991, May 16). The Financial Times, 50.

Hegde, S. P. (1988). An empirical analysis of implicit delivery options in the Treasury bond futures contract. Journal of Banking and Finance, 12, 469–492.

Kane, A., & Marcus, A. (1986). Valuation and optimal exercise of the wild card option in the Treasury bond futures market. Journal of Finance, 41, 231–248.

Kehoe, L. (1999, April 10). Compaq shares tumble after profits warning. The Financial Times, 22.

Stoll, H. R., & Whaley, R. E. (1990). The dynamics of stock index and stock index futures returns. Journal of Financial and Quantitative Analysis, 25, 441–468.

Valerio, N. (1993). Valuation of cash-settlement options containing a wild-card exercise feature. Journal of Financial Engineering, 2, 335–364.

Received May, 1999
Accepted October, 1999