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The Value of Wildcard Options

JEFF FLEMING and ROBERT E. WHALEY*

ABSTRACT

Wildcard options are embedded in many derivative contracts. They arise when the settlement price of the contract is established before the time at which the wildcard option holder must declare his intention to make or accept delivery and the exercise of the wildcard option closes out the underlying asset position. This paper provides a simple method for valuing wildcard options and illustrates the technique by valuing the sequence of wildcard options embedded in the S&P 100 index (OEX) option contract. The results show that wildcard options can account for an economically significant fraction of OEX option value.

MANY EXCHANGE-TRADED DERIVATIVE securities contain embedded delivery options. Agricultural futures contracts, for example, include a quality option that permits the short to deliver one of a number of grades of the underlying commodity. They also contain a timing option that permits the short to decide when during the delivery month the delivery will take place.

Another type of embedded delivery option is the wildcard option. A wildcard option arises when the settlement price of a futures or option contract is established before the final exercise opportunity and when exercise closes the underlying asset position. The Treasury bond (T-bond) futures contract traded at the Chicago Board of Trade, for example, contains two wildcard options. An *end-of-day* wildcard option arises because the settlement price of the T-bond futures contract is set at 2:00 P.M. central standard time (CST), and the short futures can wait until 8:00 P.M. to declare an intention to deliver. An *end-of-month* wildcard option arises because the settlement price of the T-bond futures contract is set seven business days before the end of the contract month, and the short futures can wait until the end of the month to deliver.

The American-style S&P 100 index (OEX) option contract traded at the Chicago Board Options Exchange (CBOE) also has an embedded end-of-day wildcard option. The OEX wildcard option arises because the settlement price

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of the option is set equal to the S&P 100 index level at 3:00 P.M. CST when the New York Stock Exchange closes. The OEX option holder, however, may postpone the exercise decision until 3:15 P.M. (3:20 P.M. since November 6, 1991). If the market falls (or rises) dramatically during the "wildcard period," the holder of an in-the-money long call (or put) may find it optimal to exercise his option, thereby forfeiting the remaining option premium to avoid the fifteen-minute price decline (or increase).

Little has been written about the valuation of wildcard options.[1] One possible explanation is that, because the wildcard period is generally short relative to the option's life, the wildcard option is perceived to have little value. Another possible explanation is that analytically valuing the wildcard option is cumbersome and costly since it is actually a sequence of daily wildcard options with the value of the distant wildcards conditional upon the value of wildcards nearer to expiration. This paper shows that the valuation of the wildcard option sequence can be handled easily within a binomial lattice framework and that the value of the wildcard sequence may be quite significant.

The wildcard valuation methodology developed in this paper builds upon the standard Cox-Ross-Rubinstein (1979) binomial method for valuing American-style options.[2] The procedure begins at the end of the option's life where the option value at each node simply equals the proceeds from exercise. As the procedure steps back in time, the option value at each node is computed by discounting the expected future value and then adding the wildcard option. Therefore, at each time step, the American-style option value depends not only on the current wildcard opportunity but also on all subsequent opportunities. When the recursive procedure is complete, the value of the entire sequence of wildcard opportunities is impounded in the option value.

To illustrate the methodology, the wildcard options embedded in the OEX option are valued. Simulation results indicate that the existence of the wildcard options has a significant effect on the overall option value. The wildcard feature adds as much as four percent to the value of one-week OEX call and put options. For call options, this amount is well in excess of the interest/dividend early exercise premium on calls without the wildcard; for at-the-money put options, the two amounts are approximately equal. While the wildcard option value deteriorates relative to the premium for longer-term options, it still accounts for more than two percent of the value of at-the-money options that are as far as two months from expiration. These percentages are substantial from an economic standpoint. In a *single* day of OEX option trading, wildcard premiums amount to more than $5 million!

[1] Kane and Marcus (1986) and Valerio (1989) develop recent models for the two wildcard options described above. Gay and Manaster (1986, 1991) demonstrate the profitability of trading strategies that exploit the wildcard options embedded in the T-bond futures contract.

[2] Our approach to valuing the sequence of wildcard opportunities can also be used in conjunction with other American-style option approximation methods including explicit and implicit finite difference methods (see, for example, Brennan and Schwartz (1978)) and the trinomial method (see, for example, Boyle (1988)).

This article is organized as follows. Section I develops a binomial method for valuing wildcard options. Section II applies the method to value the wildcard option embedded in OEX call and put options, and Section III addresses some practical matters regarding differential rates of volatility during the day. A short summary in Section IV concludes the article.

I. Wildcard Option Valuation

Valuing an American-style option with a series of wildcard opportunities can be handled straightforwardly using the standard Cox-Ross-Rubinstein (1979) binomial method if the length of the wildcard period matches the length of each time step.[3,4] It is simply a matter of modifying the usual early exercise bounds at each time step to account for the preestablished settlement price. Unfortunately, in most cases, the length of the wildcard period is short relative to the life of the option, so the number of time steps required in the binomial method is prohibitive. Valuing the fifteen-minute wildcard options in a thirty-day OEX option, for example, would require 96 time steps per day (i.e., 96 fifteen-minute intervals in a 24-hour day) or 2,880 time steps over the life of the option.

Our method of valuing an American-style option with wildcard opportunities avoids this computational burden. First, we set up the binomial lattice in a way such that the end of each time step coincides with the end of each wildcard period. We then proceed backwards from the end of the option's life to the present using the standard binomial method. However, at each node of each time step, we compute the value of the wildcard option and add it to the option value. Since the option values at time step $n - 1$ depend on the option values at time step n, all wildcard opportunities are embedded when the recursive procedure is complete.

This section describes in detail our wildcard option valuation method. We begin by reviewing how the binomial method can be used to value an American-style call option with no wildcard opportunities. We then modify the technique to value a wildcard-inclusive option. This involves computing wildcard option values at all nodes within the binomial lattice. The individual wildcard options are valued using a modified version of the Black-Scholes (1973) formula. Although the wildcard-inclusive valuation framework is de-

[3] Matching the length of the time step to the length of the wildcard period prevents the binomial lattice from bifurcating.

[4] From a theoretical standpoint, the binomial method can only be applied in instances when an arbitrage between the option and the underlying asset is possible. Thus, if the asset market is closed while the option market stays open (as is the case for OEX options, for example), arbitrage trading is not possible and the binomial method cannot be applied. From a practical standpoint, however, arbitrage trading can continue during the wildcard period if another claim on the asset trades. In the case of the OEX option, for example, cross-arbitrage with the S&P 500 futures is possible. Indeed, as we will discuss at greater length in Section III, the arbitrage activity between these two markets causes the comovement of their prices to be much stronger than either derivative market with the stock market.

veloped in terms of a cash settlement, American-style call option with wildcard opportunities, the framework can be easily modified to value wildcard opportunities embedded in cash settlement or delivery American-style put options or futures contracts.

A. Binomial Method for Valuing the Wildcard-exclusive Option

The Cox-Ross-Rubinstein (1979) binomial method for valuing American-style options uses the Black-Scholes (1973) option valuation assumptions. In particular, the riskless rate of interest, r, is assumed to be constant and asset prices are assumed to be lognormally distributed with a constant volatility rate, σ. Certain notation and definitions facilitate the description of the binomial method. Let X be the option's exercise price. We define N as the number of time steps during the life of the option, and T as the option's time to expiration. Let S_n^j denote the asset price at time step n, node j, where $j = 1, \ldots, n + 1$, ordered sequentially from the top of the lattice. C_n^j is the corresponding call option value. At each step, the asset return is $u = e^{\sigma\sqrt{\Delta t}}$, with probability $p = (r^* - d)/(u - d)$, or $d = 1/u$, with probability $1 - p$, where $\Delta t = T/N$ and $r^* = e^{r\Delta t}$. Working backward from the end of the call option's life, C_n^j is the maximum of the proceeds from immediate exercise and the present value of the possible option values at $n + 1$,

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

By moving backward through time and repeating these computations, the current value of an American-style option is determined.[5]

B. Binomial Method for Valuing the Wildcard-inclusive Option

To value a wildcard-inclusive call option, we adopt the wildcard-exclusive mechanics with two modifications. First, we judiciously select the number of time steps, N, in such a way that the end of each time step coincides with the end of each wildcard period. For example, if we are valuing an OEX call option which has an end-of-day wildcard option, we set N equal to the number of days to the option's expiration. Second, at each node j in each time step n, we value the wildcard option and add it to the present value of the expected future option value. That is, we replace the recursive formula (1) with

$$C_n^{*j} = \max\left[S_n^j - X, \frac{pC_{n+1}^{*j} + (1 - p)C_{n+1}^{*j+1}}{r^*} + W_n^{C^j}\right] \quad (2a)$$

$$= \max\left[S_n^j - X, C_n'^j + W_n^{C^j}\right]. \quad (2b)$$

[5] The binomial method works equally well for European-style options. The only modification necessary is to drop the early exercise bound, $S_n^j - X$, in equation (1).

C_n^{*j} is the total value of the wildcard-inclusive option at node j and time step n, and $C_n'^j(\equiv [pC_{n+1}^{*j} + (1-p)C_{n+1}^{*j+1}]/r^*)$ is the wildcard-inclusive option value excluding the value of the current wildcard, $W_n^{C^j}$.

C. Valuing Individual Wildcards

To implement (2a) or (2b), we need a valuation equation for the wildcard option. Normally, the wildcard option payoff structure is written as if we were standing at the beginning of the wildcard period, $n - w$, when the settlement price, S_{n-w}, is established, that is,

$$\tilde{W}_n^C = \begin{cases} (S_{n-w} - X) - \tilde{C}_n' & \text{if } S_{n-w} - X > \tilde{C}_n' \\ 0 & \text{if } S_{n-w} - X \leq \tilde{C}_n', \end{cases} \tag{3}$$

where w is the length of the wildcard period.[6] $\tilde{C}_n'$ is the worth of the call (which implicitly depends on the asset price, $\tilde{S}_n$) if left unexercised at the end of the wildcard period at n. If the asset price falls dramatically during the wildcard period, the net cash proceeds from exercising the call just prior to time n, $S_{n-w} - X$, may exceed the worth of the call at time n, C_n', and the wildcard option (and hence the call option) will be exercised. On the other hand, if the asset price rises, the call value rises, and the wildcard option expires worthless. The payoff contingencies of the wildcard (3) are those of a put option. Note that the wildcard option is out of the money at time $n - w$ since $C_{n-w}' > S_{n-w} - X$ if the call has any time value whatsoever.

To incorporate the wildcard option payoff structure into our binomial framework, recall that we selected the number of time steps N in such a way that the end of each time step coincided with the *end* of each wildcard period. This means that, in terms of the payoff structure (3), the value of $C_n'^j$ is known but S_{n-w}^j is not. To handle this problem, we "invert" the direction of the conditional payoff structure (3) and think of the wildcard option as having payoffs

$$\tilde{W}_n^{C^j} = \begin{cases} \tilde{S}_{n-w}^j - \left(X + C_n'^j\right) & \text{if } \tilde{S}_{n-w}^j > X + C_n'^j \\ 0 & \text{if } \tilde{S}_{n-w}^j \leq X + C_n'^j. \end{cases} \tag{4}$$

We then approximate the asset price distribution at time $n - w$, and take the expectation of (4) to value the wildcard option.

The asset price distribution at time $n - w$ conditional on the asset price being S_n^j at time n can be approximated in a number of ways. One approach is to use a second binomial lattice, with fewer time steps, for the wildcard period. Unfortunately, this means a discrete distribution of asset prices replaces the assumed continuous (lognormal) distribution under the Black-Scholes framework. If five time steps are used for the wildcard period, for

[6] The wildcard option will not rationally be exercised during the wildcard period (since the exercise proceeds cannot be collected and invested), so this European-style option payoff structure applies without loss of generality.

example, only six asset prices at the beginning of the wildcard period are possible. Another alternative is to use the lognormal asset price distribution assumption. With a lognormal distribution, more extreme moves in the asset price over the wildcard period are considered. In addition, since the wildcard option is European-style, as noted earlier, it can be valued analytically.

Our assumption regarding the asset price distribution is shown in Figure 1. The asset price at the end of the wildcard period, S_n^j, is known. Conditional upon S_n^j, the lognormal distribution for asset price at the beginning of the wildcard period, $\tilde{S}_{n-w}^j$, is developed. Then, to value the wildcard option, we take the expectation of $\tilde{W}_n^{C^j}$ as defined by (4). The value of the wildcard option at node j and time step n is

$$W_n^{C^j} = S_n^j e^{-rt_w} \mathrm{N}(d_1) - \left(X + C_n^{\prime j}\right)\mathrm{N}(d_2), \tag{5}$$

where

$$d_1 = \frac{\ln\left(\dfrac{S_n^j}{X + C_n^{\prime j}}\right) - (r - 0.5\sigma^2)t_w}{\sigma\sqrt{t_w}} \tag{5a}$$

$$d_2 = d_1 - \sigma\sqrt{t_w}\,, \tag{5b}$$

and where t_w is the length of the wildcard period (in the same units as T), r and σ are as defined previously, and $\mathrm{N}(d)$ is the cumulative unit normal density function with upper integral limit d. Note that this formula is slightly different than the Black-Scholes call option valuation formula. The differences arise from the fact that no interest is earned over the wildcard period and that the asset return is negative over the wildcard period (from n to $n - w$).

II. Simulation of OEX Option Early Exercise Premiums

To demonstrate that the sequence of end-of-day wildcard options may be quite valuable even when the length of the wildcard period is short, we simulate the values of the American-style OEX option with and without the wildcard privilege. Before turning to the simulation results, however, we must address the issue of cash dividends on the underlying S&P 100 index portfolio.

A. Valuation of OEX Options

Harvey and Whaley (1992a) show how to modify the binomial method to account for discrete cash dividend payments on the S&P 100 index portfolio. The index level is deflated by the present value of the dividend stream during the life of the option, and then the adjusted index level is used to create the binomial lattice. As we move backward from the terminal nodes in the lattice, the present value of all dividends subsequent to a given time step, PVD_n, must be added back to the index level prior to the evaluation of early exercise

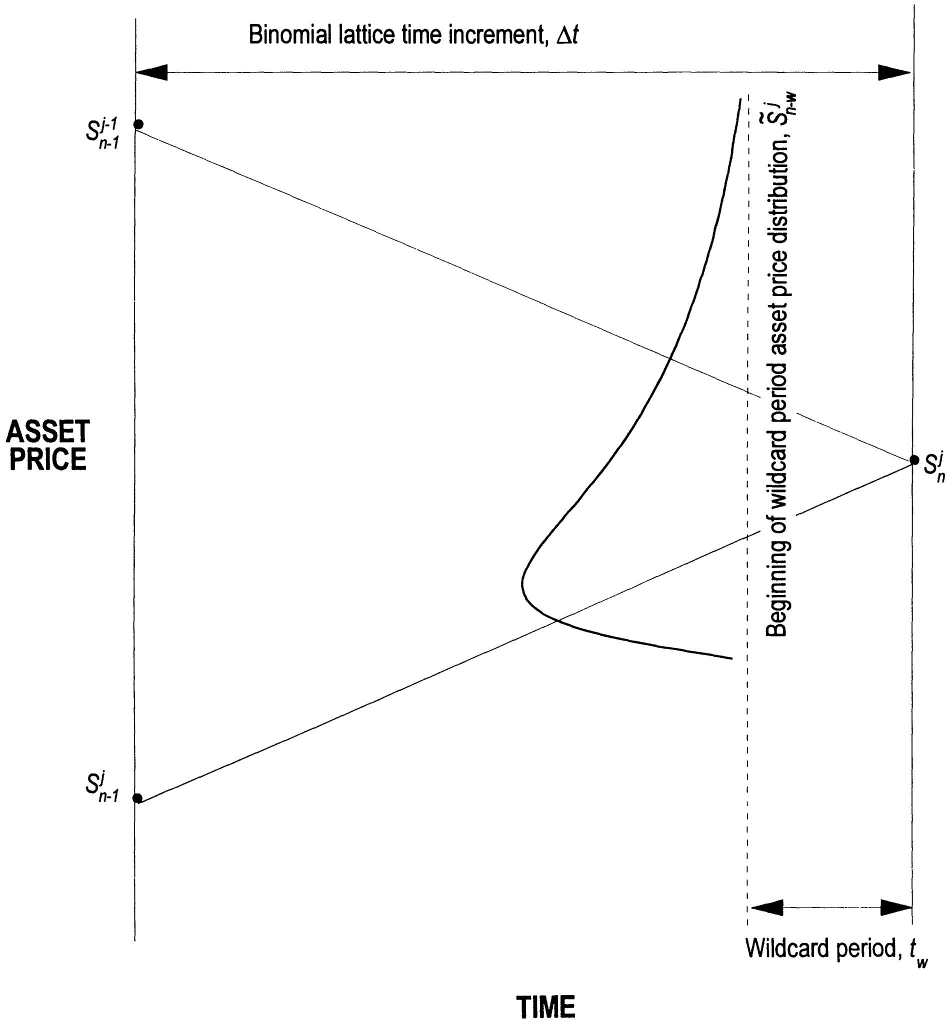

Figure 1. Valuation of the wildcard option within a binomial framework. Wildcard valuation occurs at node j of time step n in the binomial lattice. The asset price, S_n^j, is determined by an upstep from S_{n-1}^j or a down step from S_{n-1}^{j-1}. The lognormal asset price distribution at the beginning of the wildcard period, $\tilde{S}_{n-w}^j$, is based on the end-of-period asset price, S_n^j. The value of the wildcard-inclusive option is found by taking the expectation of

$$\tilde{W}_n^{C^j} = \begin{cases} \tilde{S}_{n-w}^j - (X + C_n'^j) & \text{if } \tilde{S}_{n-w}^j > X + C_n'^j \\ 0 & \text{if } \tilde{S}_{n-w}^j \le X + C_n'^j, \end{cases}$$

where X is the exercise price of the option and $C_n'^j$ is the value of an otherwise identical option, but without a wildcard option at time n.

opportunities. With discrete cash dividends, the recursive formula for wildcard-exclusive options is

$$C_n^j = \max\left[S_n^j + PVD_n - X, \frac{pC_{n+1}^j + (1-p)C_{n+1}^{j+1}}{r^*}\right], \tag{6}$$

and for the wildcard-inclusive options is

$$C_n^{*j} = \max\left[S_n^j + PVD_n - X, \frac{pC_{n+1}^{*j} + (1-p)C_{n+1}^{*j+1}}{r^*} + W_n^{C^j}\right]. \tag{7}$$

B. Simulation Details

Based on the methodology described above, we conduct simulations of OEX option values during 1991. We assume that the length of the OEX wildcard period is fifteen minutes of a 24-hour day.[7] In an attempt to make the simulations of the OEX wildcard option premium as realistic as possible, we base our analysis on actual closing S&P 100 index levels during 1991. A full year is used to account fully for the seasonal patterns in the cash dividends of the S&P 100 index portfolio (see Harvey and Whaley (1992b)). Each day during the year, values are computed for all options with exercise prices within ± 10 percent of the index level. Exercise prices are assumed to be at five-dollar increments. At each exercise price, eight expiration dates are considered. These dates are assumed to be the nearest eight Saturdays which are at least four days from the day of valuation. For example, if valuation takes place on a Tuesday, the coming Saturday is the nearest expiration considered, with the remaining expiration dates being the following seven Saturdays. If the valuation occurs on a Wednesday, the following Saturday is the nearest expiration.

In addition to the expirations and strike prices, estimates of the riskless rate of interest, the cash dividends paid during the life of the option, and the volatility rate of the underlying index are required. Interest rates are proxied with the Treasury bill (T-bill) quotes reported in the *Wall Street Journal*. An average of the bid and ask discounts for the T-bill whose maturity most closely matches option expiration is used to determine the effective interest rate.[8] The daily cash dividends for the S&P 100 index are obtained from the *S&P 100 Information Bulletin*.

To proxy for the OEX volatility rate each day during the sample period, we use the implied volatility of actual, at-the-money, OEX call (or put) option prices. The implied volatility for the call (or put) is estimated using all nearby, but with at least fifteen days to expiration, at-the-money call (or put) option transaction prices within a ten-minute window centered around the

[7] On November 6, 1991, the wildcard period for the OEX option was extended until 3:20 P.M. to allow market makers an additional five minutes to effect exercise.

[8] If the option is nearer than thirty days to expiration, we use the T-bill with the nearest maturity in excess of thirty days.

New York Stock Exchange close. The estimate is computed using a nonlinear least squares regression of transaction prices on theoretical values, where theoretical values are computed using the wildcard-inclusive binomial method.

By way of background, two aspects of the S&P 100 index during 1991 are worth noting. First, the daily closing index level rose from a level of about 300 to in excess of 380 over the year. Much of this 27 percent gain was realized during the first quarter of the year, with a smaller but nonetheless sharp increase occurring at year end. During most of the year (i.e., March through November), the index stayed within a 20-point range. Second, the daily implied volatility rate for the S&P 100 index exceeded 30 percent at the beginning of the year, and then quickly dropped off to a level of about 15 percent and within a range of about 12 to 18 percent for the remainder of the year. Since the index level and volatility rate during 1991 are not abnormal by historical standards, the simulation results, which are based on the daily values of these variables, provide a good sense for typical values of the wildcard privilege embedded in the OEX option.

C. Wildcard Option Valuation Results

For each day during the simulation period, the binomial method is applied to value European-style, wildcard-exclusive American-style, and wildcard-inclusive American-style options with OEX option market characteristics. The wildcard-exclusive American-style call option valuation uses the recursive formula (6), and the wildcard-inclusive valuation uses (7) in combination with the valuation formula (5). European-style option valuation relies on (6), absent the early exercise bound, $S_n^j + PVD_n - X$.

Prior to discussing the simulation results, it is important that we distinguish clearly between the different motives for exercising OEX options early. Absent the wildcard, OEX calls may be exercised early depending upon the size of the daily cash dividends on the index, which are received if the call is exercised early, relative to the present value of the interest income that can be earned implicitly by deferring exercise. For OEX puts, the early exercise dilemma is whether or not to forfeit the interest income that can be earned by immediate exercise in favor of waiting and watching the index level drop as the cash dividends are paid. Since both the OEX call and the OEX put may be exercised early absent the wildcard, we call the value of this privilege the "interest/dividend early exercise premium." It is identified by taking the difference between the wildcard-exclusive American-style option value and the European-style option value. Distinct from the interest income–cash dividend motives, however, the OEX's wildcard privilege may provide an additional incentive for early exercise. We call the value of this privilege the "wildcard early exercise premium." It is identified by taking the difference between the wildcard-inclusive American-style option value and the wildcard-exclusive value.

Panel A of Tables I and II contain the average wildcard-inclusive call and put option values, respectively, over the simulation period. The number of

Table I

Simulation of S&P 100 Call Option Value, Interest/Dividend Early Exercise Premium, and Wildcard Early Exercise Premium by Option Moneyness (M) and by Days to Expiration (T) during the Period January through December 1991

Panel A contains the average wildcard-inclusive American-style option value. Panel B contains the wildcard-exclusive American-style option value less the European-style option value. Panel C contains wildcard-inclusive American-style option value less the wildcard-exclusive American-option value. Moneyness for call options is defined as $M \equiv 100*(S/X - 1)$, where S is the index level and X is the exercise price of the call. Negative values of m are therefore out-of-the-money options and positive values are in-the-money options.

	Days to Expiration (T)								
Moneyness (M)	4–10	11–17	18–24	25–31	32–38	39–45	46–52	53–59	No. of Observations
	Panel A: Average Wildcard-inclusive Option Value								
$-10.0 \leq M < -7.5$	0.004	0.037	0.121	0.256	0.435	0.651	0.890	1.148	3,520
$-7.5 \leq M < -5.0$	0.027	0.165	0.413	0.728	1.078	1.454	1.841	2.230	3,568
$-5.0 \leq M < -2.5$	0.246	0.781	1.385	1.988	2.572	3.146	3.698	4.228	3,632
$-2.5 \leq M < 0.0$	1.643	2.839	3.813	4.662	5.424	6.142	6.806	7.428	3,640
$0.0 \leq M < 2.5$	6.332	7.514	8.485	9.331	10.091	10.815	11.481	12.102	3,576
$2.5 \leq M < 5.0$	13.919	14.483	15.083	15.682	16.264	16.851	17.413	17.946	3,432
$5.0 \leq M < 7.5$	22.566	22.829	23.123	23.458	23.818	24.225	24.633	25.034	3,664
$7.5 \leq M < 10.0$	31.623	31.819	31.994	32.179	32.383	32.638	32.904	33.174	3,592
No. of observations	3,578	3,578	3,578	3,578	3,578	3,578	3,578	3,578	

Table I—*Continued*

Moneyness (M)	Days to Expiration (T) 4–10	11–17	18–24	25–31	32–38	39–45	46–52	53–59
Panel B: Average Interest/Dividend Early Exercise Premium								
$-10.0 \leq M < -7.5$	0.0000	0.0000	0.0001	0.0006	0.0010	0.0013	0.0020	0.0028
$-7.5 \leq M < -5.0$	0.0000	0.0001	0.0006	0.0016	0.0029	0.0038	0.0045	0.0067
$-5.0 \leq M < -2.5$	0.0001	0.0011	0.0027	0.0055	0.0079	0.0096	0.0118	0.0143
$-2.5 \leq M < 0.0$	0.0018	0.0068	0.0114	0.0149	0.0174	0.0210	0.0249	0.0279
$0.0 \leq M < 2.5$	0.0191	0.0271	0.0318	0.0353	0.0366	0.0400	0.0495	0.0514
$2.5 \leq M < 5.0$	0.0533	0.0618	0.0649	0.0628	0.0606	0.0654	0.0722	0.0752
$5.0 \leq M < 7.5$	0.0635	0.1016	0.1031	0.0991	0.0946	0.0960	0.1018	0.1096
$7.5 \leq M < 10.0$	0.0683	0.1125	0.1316	0.1323	0.1285	0.1268	0.1362	0.1405
Panel C: Average Wildcard Early Exercise Premium								
$-10.0 \leq M < -7.5$	0.0001	0.0008	0.0025	0.0051	0.0083	0.0118	0.0153	0.0188
$-7.5 \leq M < -5.0$	0.0005	0.0034	0.0083	0.0138	0.0194	0.0248	0.0297	0.0343
$-5.0 \leq M < -2.5$	0.0050	0.0157	0.0263	0.0354	0.0432	0.0500	0.0560	0.0611
$-2.5 \leq M < 0.0$	0.0331	0.0538	0.0671	0.0761	0.0834	0.0893	0.0942	0.0978
$0.0 \leq M < 2.5$	0.1217	0.1297	0.1343	0.1372	0.1393	0.1418	0.1430	0.1448
$2.5 \leq M < 5.0$	0.2084	0.2097	0.2040	0.1992	0.1957	0.1938	0.1923	0.1903
$5.0 \leq M < 7.5$	0.2414	0.2609	0.2598	0.2537	0.2479	0.2421	0.2388	0.2358
$7.5 \leq M < 10.0$	0.2463	0.2793	0.2862	0.2843	0.2818	0.2786	0.2750	0.2704

Table II

Simulation of S&P 100 Put Option Value, Interest/Dividend Early Exercise Premium, and Wildcard Early Exercise Premium by Option Moneyness (M) and by Days to Expiration (T) during the Period January through December 1991

Panel A contains the average wildcard-inclusive American-style option value. Panel B contains the wildcard-exclusive American-style option value less the European-style option value. Panel C contains wildcard-inclusive American-style option value less the wildcard-exclusive American-option value. Moneyness for put options is defined as $M \equiv 100*(1 - S/X)$, where S is the index level and X is the exercise price of the put. Negative values of M are therefore out-of-the-money options and positive values are in-the-money options.

	Days to Expiration (T)								
Moneyness (M)	4–10	11–17	18–24	25–31	32–38	39–45	46–52	53–59	No. of Observations
Panel A: Average Wildcard-inclusive Option Value									
$-10.0 \le M < -7.5$	0.002	0.019	0.064	0.142	0.248	0.373	0.513	0.666	3,592
$-7.5 \le M < -5.0$	0.019	0.122	0.308	0.545	0.809	1.080	1.356	1.634	3,664
$-5.0 \le M < -2.5$	0.204	0.651	1.154	1.649	2.124	2.567	2.987	3.389	3,432
$-2.5 \le M < 0.0$	1.479	2.554	3.413	4.144	4.790	5.357	5.881	6.368	3,576
$0.0 \le M < 2.5$	5.981	7.048	7.899	8.618	9.252	9.802	10.312	10.785	3,640
$2.5 \le M < 5.0$	13.824	14.249	14.716	15.182	15.631	16.035	16.426	16.802	3,632
$5.0 \le M < 7.5$	22.679	22.812	22.974	23.167	23.385	23.597	23.820	24.051	3,568
$7.5 \le M < 10.0$	31.431	31.504	31.564	31.634	31.719	31.802	31.901	32.012	3,520
No. of observations	3,578	3,578	3,578	3,578	3,578	3,578	3,578	3,578	

Table II—*Continued*

Moneyness (M)	Days to Expiration (T) 4–10	11–17	18–24	25–31	32–38	39–45	46–52	53–59
Panel B: Average Interest/Dividend Early Exercise Premium								
$-10.0 \leq M < -7.5$	0.0000	0.0001	0.0004	0.0009	0.0017	0.0031	0.0048	0.0068
$-7.5 \leq M < -5.0$	0.0001	0.0007	0.0021	0.0042	0.0068	0.0105	0.0146	0.0187
$-5.0 \leq M < -2.5$	0.0012	0.0047	0.0096	0.0151	0.0215	0.0290	0.0371	0.0455
$-2.5 \leq M < 0.0$	0.0103	0.0216	0.0332	0.0442	0.0566	0.0696	0.0822	0.0940
$0.0 \leq M < 2.5$	0.0527	0.0712	0.0902	0.1112	0.1304	0.1516	0.1696	0.1884
$2.5 \leq M < 5.0$	0.1500	0.1825	0.2098	0.2369	0.2642	0.2944	0.3164	0.3391
$5.0 \leq M < 7.5$	0.2286	0.3343	0.3896	0.4345	0.4682	0.5097	0.5484	0.5757
$7.5 \leq M < 10.0$	0.2484	0.4213	0.5470	0.6394	0.7091	0.7817	0.8310	0.8751
Panel C: Average Wildcard Early Exercise Premium								
$-10.0 \leq M < -7.5$	0.0000	0.0004	0.0013	0.0028	0.0048	0.0071	0.0095	0.0119
$-7.5 \leq M < -5.0$	0.0004	0.0026	0.0065	0.0108	0.0154	0.0198	0.0240	0.0276
$-5.0 \leq M < -2.5$	0.0043	0.0137	0.0231	0.0312	0.0384	0.0443	0.0495	0.0539
$-2.5 \leq M < 0.0$	0.0320	0.0520	0.0650	0.0739	0.0810	0.0863	0.0901	0.0937
$0.0 \leq M < 2.5$	0.1213	0.1300	0.1350	0.1388	0.1419	0.1429	0.1438	0.1446
$2.5 \leq M < 5.0$	0.2092	0.2264	0.2212	0.2147	0.2113	0.2079	0.2046	0.2023
$5.0 \leq M < 7.5$	0.2135	0.2506	0.2671	0.2720	0.2708	0.2665	0.2623	0.2577
$7.5 \leq M < 10.0$	0.2107	0.2439	0.2599	0.2738	0.2848	0.2885	0.2904	0.2911

options in each category are also provided. Panel B contains the average interest/dividend early exercise premium, and Panel C contains the average value of the wildcard premium.

The results reported in Panel B of Tables I and II show that the interest/dividend early exercise premium of the OEX option contributes significantly to overall value. The premium is larger for put options than for call options. The premium for a one-week, slightly in-the-money call option, for example, averages about two cents while the premium for a put with the same characteristics is about five cents. The size of the premium also increases with time to expiration and moneyness. The slightly in-the-money options with about two months to expiration, for example, have interest/dividend premiums of five cents and 19 cents for the call and the put, respectively. Two-month, deep in-the-money calls and puts have premiums of 14 cents and 88 cents, respectively.

The results in Panel C indicate that the wildcard premium also is an important component of OEX option value. The wildcard feature, for example, accounts for about 12 cents of the value of slightly in-the-money call and put options. Interestingly, the results in Panel C of Tables I and II indicate that the wildcard premiums are approximately the same for calls and puts with the same moneyness and time to expiration characteristics. This is not surprising since the large index level movements during the wildcard period are almost as likely to be up (favoring the put option holder) as down (favoring the call option holder).

The wildcard value increases as time to expiration increases. This may seem counterintuitive since the wildcard privilege should be most significant when the option's time value, which is forfeited upon exercise, is smaller (i.e., short-term options). Long-term options, however, contain all of the wildcard options of their short-term counterparts,[9] so the dollar value of the wildcard feature actually increases with time to expiration. The rate of increase in wildcard value, however, decreases with time to expiration. In other words, the wildcard options more distant from expiration do, in fact, appear to contribute a smaller amount to option value than wildcards nearer to expiration.

The wildcard value also generally increases as the moneyness of the option increases. The intuition underlying this result is that options further in the money have a greater sensitivity to asset price movement, and hence, a greater likelihood that an adverse asset price move (which causes a decline in option value) will trigger exercise. A second interesting result that appears in Panel C of Table II is that, for short times to expiration, the value of the wildcard in the put option increases and then begins to decrease as the option becomes more in the money. It appears that, beyond a certain degree of moneyness, the put is almost certain to be exercised early, independent of the

[9] For example, a ten-day option involves a wildcard option for each trading day before expiration. Therefore, it contains the wildcard ten days to expiration, as well as every wildcard embedded in an equivalent expiration nine-day option.

index movement during the last fifteen minutes of the day, so the wildcard option becomes less valuable.

Table III reports the average wildcard premium as a fraction of the total early exercise premium. A value of 1.0, for example, indicates that the early exercise premium is entirely attributable to the wildcard. A value of 0.0, on the other hand, indicates that the early exercise premium is attributable only to interest income–cash dividend incentives. For call options, the wildcard premium exceeds the interest/dividend early exercise premium for all option values simulated, even for the deep in-the-money, long time-to-expiration calls. All of the values in Panel A of Table III are well in excess of 0.5. For put

Table III

Simulation of the Value of the Wildcard Early Exercise Premium Relative to the Total Early Exercise Premium for S&P 100 Options by Option Moneyness (M) and by Days to Expiration (T) during the Period January through December 1991

The wildcard premium is the difference between the wildcard-inclusive and wildcard-exclusive American-style option values; the total early exercise premium is the difference between the wildcard-inclusive American-style option value and the European-style option value. Moneyness for call options is defined as $M \equiv 100*(S/X - 1)$ and moneyness for put options is defined as $M \equiv 100*(1 - S/X)$, where S is the index level and X is the exercise price of the option. Negative values of M are therefore out-of-the-money options and positive values are in-the-money options. Options for which the total early exercise premium is less than $0.001 are omitted.

	Days to Expiration (T)								No. of
Moneyness (M)	4–10	11–17	18–24	25–31	32–38	39–45	46–52	53–59	Observations
Panel A: Call Options									
$-10.0 \leq M < -7.5$	1.000	0.969	0.961	0.944	0.942	0.927	0.910	0.908	2,448
$-7.5 \leq M < -5.0$	0.993	0.965	0.950	0.940	0.928	0.914	0.907	0.893	3,018
$-5.0 \leq M < -2.5$	0.982	0.955	0.935	0.921	0.914	0.903	0.885	0.880	3,472
$-2.5 \leq M < 0.0$	0.965	0.928	0.911	0.903	0.897	0.888	0.873	0.866	3,638
$0.0 \leq M < 2.5$	0.921	0.901	0.889	0.876	0.876	0.871	0.849	0.841	3,576
$2.5 \leq M < 5.0$	0.892	0.869	0.858	0.855	0.859	0.849	0.842	0.836	3,432
$5.0 \leq M < 7.5$	0.884	0.836	0.828	0.828	0.831	0.829	0.822	0.809	3,664
$7.5 \leq M < 10.0$	0.880	0.831	0.805	0.800	0.802	0.808	0.798	0.792	3,592
No. of observations	2,589	3,050	3,375	3,521	3,571	3,578	3,578	3,578	
Panel B: Put Options									
$-10.0 \leq M < -7.5$	0.840	0.814	0.768	0.736	0.709	0.679	0.656	0.633	2,278
$-7.5 \leq M < -5.0$	0.825	0.776	0.737	0.707	0.681	0.651	0.625	0.602	3,053
$-5.0 \leq M < -2.5$	0.793	0.743	0.706	0.676	0.644	0.614	0.585	0.559	3,297
$-2.5 \leq M < 0.0$	0.768	0.714	0.671	0.637	0.605	0.571	0.546	0.523	3,574
$0.0 \leq M < 2.5$	0.707	0.662	0.620	0.578	0.548	0.513	0.488	0.463	3,640
$2.5 \leq M < 5.0$	0.608	0.584	0.546	0.511	0.483	0.450	0.427	0.407	3,632
$5.0 \leq M < 7.5$	0.516	0.472	0.453	0.431	0.412	0.382	0.360	0.342	3,568
$7.5 \leq M < 10.0$	0.493	0.409	0.372	0.347	0.333	0.307	0.292	0.281	3,520
No. of observations	2,570	2,986	3,281	3,445	3,553	3,571	3,578	3,578	

options, the results are mixed. For short time-to-expiration, out-of-the-money puts, the wildcard premium exceeds the interest/dividend premium. On the other hand, for longer term, in-the-money options, the interest/dividend premium is more valuable.

III. Some Practical Considerations in Valuing OEX Options

In applying the wildcard option valuation framework to OEX options, two practical considerations merit discussion. First, traders use the S&P 500 futures rather than the reported S&P 100 index level to value OEX options. As a general matter, this can be verified by examining intraday price movements. Fleming, Ostdiek, and Whaley (1993), for example, show that the contemporaneous correlation between five-minute OEX option and S&P 500 futures returns is much stronger than the correlation between OEX options and the underlying cash index. In fact, they show that OEX option returns lead S&P 100 index returns by about five minutes, even after correcting for the infrequent trading of the index stocks.

The relation between the OEX options and the S&P 500 futures becomes particularly important during the wildcard period. At 3:00 P.M., the stock market closes, but OEX option holders have until 3:15 P.M. (now, 3:20 P.M) to decide whether or not to exercise. As discussed in Section I, the exercise decision weighs the net cash proceeds from exercise (which are established at 3:00 P.M. when the settlement price is set) against the value of the option if left unexercised. The value of the unexercised option, however, depends on the true value of the S&P 100 index at 3:15 P.M. Since the stock market is closed, the reported S&P 100 index level is not a sensible proxy.[10] Instead, traders use a proxy based on the nearby S&P 500 futures price. To estimate the level of the S&P 100 cash index from the S&P 500 futures, estimates of the basis between the S&P 500 futures and S&P 500 cash and between the S&P 500 cash and the S&P 100 cash are required. The futures/cash basis can be computed straightforwardly using the riskless interest rate and S&P 500 cash dividends. Given the overlapping compositions of the S&P 500 and S&P 100 cash indexes, the S&P 500 cash/S&P 100 cash basis can be estimated from recent historical behavior.

A second practical consideration important in the valuation of OEX options is the volatility rate during the wildcard period. Until now, we have implicitly assumed that the volatility rate is constant throughout the day. While this assumption seems appropriate from a theoretical standpoint, realized return volatility is considerably higher during the trading day than it is overnight. In this section, we assess the effect of more plausible volatility rate assumptions.

[10] Even if the stock market is open, the S&P 500 futures offers a better proxy for the true S&P 100 cash index level than does the reported S&P 100 index level because the reported index is based on last transaction prices of the component stocks and the component stocks do not trade continuously.

The first step in the analysis is to develop an estimate of the ratio of return volatility during the wildcard period to close-to-close (one day) volatility. As a proxy for the S&P 100 volatility, we use the historical return volatility of the nearby S&P 500 futures contract with at least one week to expiration.[11] Four returns are measured each day: (a) trading day return (open to 3:00 P.M.), (b) wildcard period return (3:00 to 3:15 P.M.), (c) overnight return (3:15 P.M. to the following day's open), and (d) close-to-close return (3:15 P.M. on day t to 3:15 P.M. on day $t + 1$). With each series, return volatility (i.e., the standard deviation of the logarithms of the price relatives) is computed. A summary of the return volatility estimates is reported in Table IV.

The return volatilities in Table IV confirm previous findings (e.g., Oldfield and Rogalski (1980), French and Roll (1986), and Stoll and Whaley (1990)). Although the trading day is only a third of the length of the overnight period, the trading day volatility swamps the overnight volatility. In the overall sample, trading day volatility is 0.01022 and overnight volatility is 0.00405. Adjusting these figures by the lengths of the periods (6.75 hours and 17.25 hours, respectively), the return volatility (standard deviation) rate is more than four ($\approx (0.01022/\sqrt{6.75})/(0.00405/\sqrt{17.25})$) times larger during the trading day than it is overnight.

More relevant to this study, however, are the volatility ratios reported in the bottom panel of the table. The volatility ratios are the observed volatility rate for the wildcard period relative to the observed volatility rates for the trading day, overnight, and close-to-close periods, respectively. Of particular interest is the fact that the wildcard period has a volatility rate 1.6 times higher than the close-to-close volatility rate. This implies that the simulations of the last section (which implicitly assumed a ratio equal to one) understate the importance of the OEX option wildcard.

The wildcard-inclusive option valuation methodology can easily be modified to account for higher volatility during the wildcard period. It is simply a matter of adjusting the volatility parameter in the wildcard option formula (5). Since the volatility rate, σ, applies to a daily (close-to-close) interval, we scale σ by the volatility factor, v, to reflect the increased volatility during the wildcard period. The "adjusted" wildcard option valuation formula is

$$W_n^{C^j} = S_n^j e^{-rt_w} \mathrm{N}(d_1) - \left(X + C_n'^j\right)\mathrm{N}(d_2), \tag{8}$$

where

$$d_1 = \frac{\ln\left(\dfrac{S_n^j}{X + C_n'^j}\right) - (r - 0.5v^2\sigma^2)t_w}{v\sigma\sqrt{t_w}} \tag{8a}$$

$$d_2 = d_1 - v\sigma\sqrt{t_w}\,. \tag{8b}$$

[11] The S&P 500 futures sample begins with the inception of the contract on April 21, 1982 and runs through March 31, 1991. The sample excludes the week of the October 1987 market crash, October 19–23, 1987.

Table IV
Return Volatility of the Nearby S&P 500 Futures Contract during the Period April 21, 1982 through March 31, 1991

Volatility is defined as the standard deviation of the natural logarithm of the price changes and is computed using four different intervals: open to 3:00 P.M. (trading day), 3:00–3:15 P.M. (wildcard), 3:15 P.M. to open the following day (overnight), and 3:15–3:15 P.M. (close to close) each day during the sample period. The variance ratio is the return variance of the wildcard period per unit of time divided by the return variance per unit of time for one of the remaining three intervals, that is,

$$\text{Variance ratio} = \frac{\sigma_w^2/0.25}{\sigma_i^2/\text{hours}_i},$$

where σ_w^2 is the variance during the wildcard period, 0.25 is the length of the wildcard period in hours, and σ_i^2 and hours_i are the variance and the length of time in hours of the ith interval (i.e., trading, overnight, or close to close). The volatility ratio is the square root of the variance ratio. The October 1987 crash week, October 19 through October 23, is excluded from the sample.

Year	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	All
No. of observations	177	252	253	253	253	248	253	252	253	61	2,255
Return Volatilities											
Period											
Trading day	0.01472	0.00899	0.00807	0.00655	0.00986	0.01353	0.01043	0.00923	0.00986	0.01027	0.01022
Wildcard	0.00325	0.00163	0.00134	0.00123	0.00151	0.00227	0.00179	0.00113	0.00183	0.00156	0.00180
Overnight	0.00562	0.00373	0.00296	0.00203	0.00319	0.00500	0.00501	0.00304	0.00490	0.00448	0.00405
Close to close	0.01650	0.00990	0.00873	0.00704	0.01064	0.01347	0.01209	0.00964	0.01103	0.01112	0.01105
Variance Ratios											
Period											
Trading day	1.2	0.8	0.7	0.9	0.6	0.7	0.8	0.4	0.9	0.6	0.8
Overnight	23.8	13.6	14.5	25.9	15.5	14.3	8.8	9.6	9.6	8.3	13.8
Close to close	3.7	2.6	2.2	2.9	1.9	2.7	2.1	1.3	2.6	1.9	2.6
Volatility Ratios											
Period											
Trading day	1.1	0.9	0.8	0.9	0.8	0.9	0.9	0.6	0.9	0.8	0.9
Overnight	4.9	3.7	3.8	5.1	3.9	3.8	3.0	3.1	3.1	2.9	3.7
Close to close	1.9	1.6	1.5	1.7	1.4	1.7	1.4	1.2	1.6	1.4	1.6

Where $v = 1$, the wildcard period volatility rate is the same as the volatility during any other fifteen-minute interval during the day—the case described in the simulation results of the last section. At the other extreme is where overnight volatility is assumed to be zero and the volatility rate during the wildcard period is assumed to be like that during any other fifteen-minute interval of the 6.75-hour trading day. This implies that the volatility factor, v, is 1.9.[12] Finally, between the two extremes is the empirical estimate of $v = 1.6$. Since this value is based on actual return volatilities, we focus our discussion primarily on its simulation results, and summarize the results using $v = 1$ and $v = 1.9$ in Figure 2.

Table V contains the simulation results for a volatility adjustment factor of 1.6 for a variety of moneyness levels. The table values are the average wildcard premium as a proportion of total option value. For short-term options, the relative pricing importance of the wildcard is greatest for at-the-money options. On average, about four percent of the value of these options is attributable to the wildcard premium. The relative values also are quite high for longer-term, out-of-the-money calls and puts. As time to expiration continues to increase, however, the relative value of the wildcard privilege diminishes for all moneyness categories. Presumably, the value of incremental wildcards in options with longer times to expiration becomes lower relative to the larger time value (greater cost of wildcard exercise). In none of the cases considered does the wildcard premium constitute less than one percent of option value.

Figure 2 compares the magnitudes of the wildcard premiums for at-the-money options under the three different volatility rate adjustment assumptions. The wildcard premium nearly doubles in size at all times to expiration when the volatility factor is increased from $v = 1$ to $v = 1.6$. At $v = 1.9$, the wildcard premium constitutes nearly five percent of the value of short-term options.

The economic significance of these wildcard option valuation results can be assessed by considering OEX trading volume. Total OEX volume in 1991 was nearly 64,000,000 contracts. Assume, for the sake of argument, that all OEX option trades were thirty-day, at-the-money options. The simulation results show that 2.9 percent of this value is attributable to the wildcard premium. With an average option value for these options of about \$7.04, our simulations imply that the aggregate wildcard premiums embedded in OEX options during 1991 amounted to (\$7.04 $\times$ 0.029 $\times$ 100 $\times$ 64,000,000 =) \$1.31 billion—an average of over \$5 million each trading day. Clearly, the wildcard option is important.

[12] If the wildcard period is fifteen minutes and we consider a 6.75-hour rather than a 24-hour day, the wildcard volatility rate is $\sqrt{24/6.75} = 1.9$ times larger than the close-to-close volatility rate.

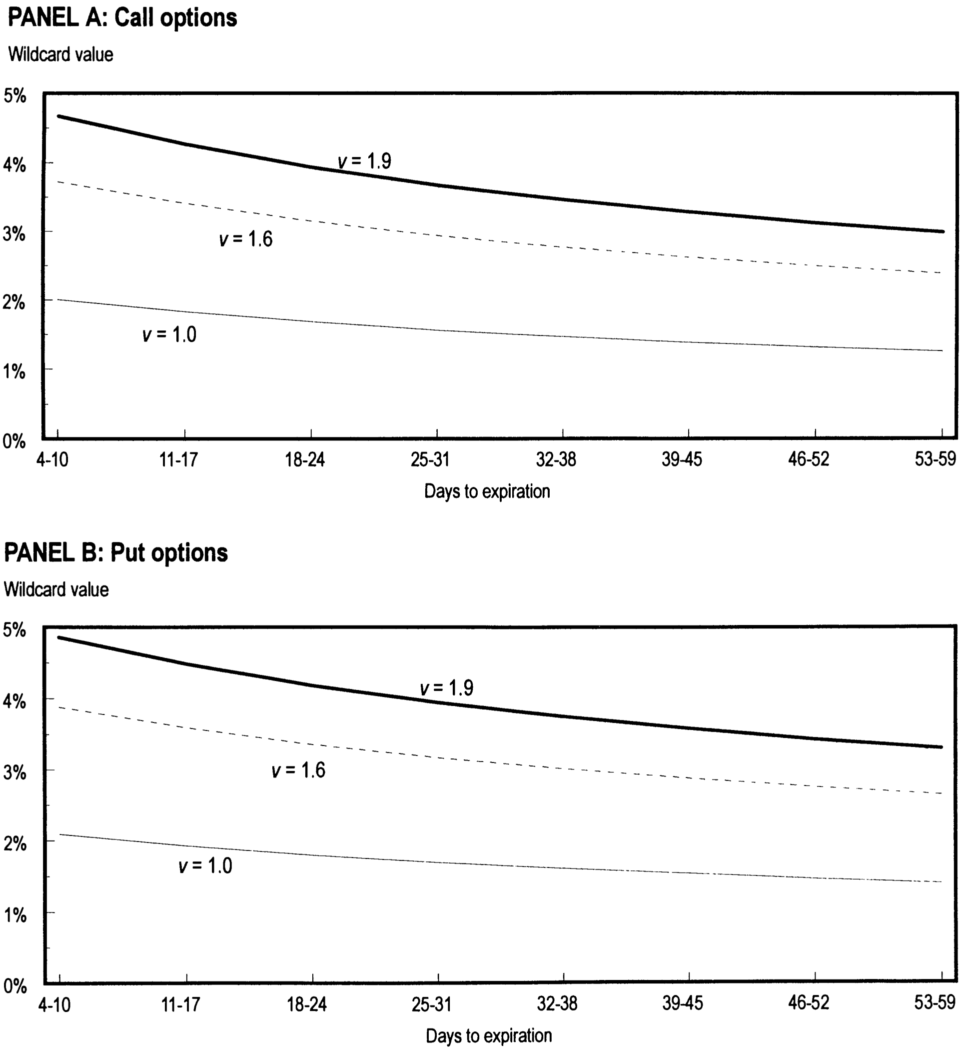

Figure 2. Simulation of the wildcard early exercise premium for at-the-money options as a percentage of the wildcard-inclusive option value by time to expiration and by wildcard period volatility adjustment factor (v) during the period January through December 1991. The wildcard premium is the difference between the wildcard-inclusive and wildcard-exclusive American-style option values. Wildcard-inclusive valuation is conducted for three volatility adjustment factors: $v = 1.0$ is where the volatility rate is assumed to be constant through a 24-hour day, and $v = 1.9$ is where overnight volatility is zero and volatility rate is assumed to be constant throughout the 6.75-hour trading day. The volatility adjustment factor, $v = 1.6$, is the ratio of realized volatility rate during the fifteen-minute wildcard period to realized close-to-close volatility rate for S&P 500 futures returns during the period April 1982 through March 1991.

Table V

Simulation of the Value of the Wildcard Early Exercise Premium (Using a Volatility Adjustment Factor of 1.6) Relative to the Wildcard-Inclusive Option Value by Option Moneyness (M) and by Days to Expiration (T) during the Period January through December 1991

The wildcard premium is the difference between the wildcard-inclusive and wildcard-exclusive American-style option values. Moneyness for call options is defined as $M \equiv 100*(S/X - 1)$ and moneyness for put options is defined as $M \equiv 100*(1 - S/X)$, where S is the index level and X is the exercise price of the option. Negative values of M are therefore out-of-the-money options and positive values are in-the-money options. Option values less than \$0.001 are omitted.

	Days to Expiration (T)								
Moneyness (M)	4–10	11–17	18–24	25–31	32–38	39–45	46–52	53–59	No. of observations
Panel A: Call Options									
$-10.0 \le M < -7.5$	0.0352	0.0368	0.0378	0.0365	0.0349	0.0334	0.0320	0.0306	3,062
$-7.5 \le M < -5.0$	0.0340	0.0373	0.0369	0.0351	0.0334	0.0317	0.0302	0.0289	3,370
$-5.0 \le M < -2.5$	0.0340	0.0372	0.0353	0.0332	0.0314	0.0297	0.0283	0.0271	3,609
$-2.5 \le M < 0.0$	0.0380	0.0357	0.0330	0.0307	0.0289	0.0273	0.0260	0.0248	3,640
$0.0 \le M < 2.5$	0.0360	0.0324	0.0297	0.0277	0.0261	0.0247	0.0235	0.0226	3,576
$2.5 \le M < 5.0$	0.0274	0.0271	0.0255	0.0240	0.0228	0.0217	0.0209	0.0201	3,432
$5.0 \le M < 7.5$	0.0191	0.0212	0.0211	0.0205	0.0198	0.0190	0.0184	0.0178	3,664
$7.5 \le M < 10.0$	0.0138	0.0161	0.0167	0.0167	0.0165	0.0162	0.0158	0.0154	3,592
No. of observations	2,990	3,488	3,577	3,578	3,578	3,578	3,578	3,578	
Panel B: Put Options									
$-10.0 \le M < -7.5$	0.0303	0.0375	0.0389	0.0384	0.0373	0.0359	0.0346	0.0334	2,988
$-7.5 \le M < -5.0$	0.0342	0.0396	0.0390	0.0375	0.0360	0.0344	0.0329	0.0317	3,434
$-5.0 \le M < -2.5$	0.0364	0.0391	0.0374	0.0357	0.0340	0.0324	0.0309	0.0298	3,405
$-2.5 \le M < 0.0$	0.0400	0.0379	0.0355	0.0335	0.0318	0.0302	0.0287	0.0276	3,576
$0.0 \le M < 2.5$	0.0378	0.0345	0.0320	0.0302	0.0288	0.0274	0.0262	0.0253	3,640
$2.5 \le M < 5.0$	0.0282	0.0296	0.0282	0.0266	0.0255	0.0245	0.0235	0.0228	3,632
$5.0 \le M < 7.5$	0.0179	0.0210	0.0220	0.0222	0.0219	0.0214	0.0209	0.0203	3,568
$7.5 \le M < 10.0$	0.0128	0.0152	0.0161	0.0168	0.0173	0.0174	0.0174	0.0173	3,520
No. of observations	2,918	3,391	3,564	3,578	3,578	3,578	3,578	3,578	

IV. Conclusions

This study provides a simple binomial method for valuing wildcard options embedded in various derivative security contracts. When the method is applied to value OEX options, the fifteen-minute wildcard privilege that occurs each day during the option's life is shown to add as much as four percent to the value of very short-term, near-the-money, OEX options. For longer times to expiration, the wildcard premium decreases as a proportion of option value. Even for two-month, at -the-money calls and puts, however, the wildcard premium constitutes more than two percent of option value. Clearly, the fifteen-minute wildcard privilege in OEX options is valuable. But this likely means that for other derivative contracts, where the wildcard period is hours or sometimes days, the wildcard privilege is even more valuable. The methodology outlined in this study should be useful in assessing such values.

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