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ABSTRACT

The Chicago Board Options Exchange concurrently listed European-style and American-style options on the Standard and Poor's 500 Index from April 2, 1986 through June 20, 1986. We match near-the-money American option quotes with the most nearly contemporaneous, otherwise identical, European option quote. In this unique sample, the bid-ask spread for the American options is twice as large as the bid-ask spread for the European options. We find that the differences in the size of the bid-ask spreads and non-contemporaneous observations create an errors-in-variables problem that, if ignored, contaminates direct measures of the early exercise premium for American options. Our findings call into question other empirical measures of the early exercise premium that do not take into account these microstructure effects. We illustrate our errors-in-variable interpretation with a simulation of regressing American trades on European trades.

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Market Microstructure Effects on the Direct Measurement of the Early Exercise Premium in S&P 500 Index Options

Free disposal dictates that the value of an American option must be equal to the value of an identical European option plus a premium for the right to exercise the American option before expiration. Because most options are American-style, valuing this early exercise premium correctly is of interest to practitioners and researchers alike. The first investigations into the size of the early exercise premium attempted the valuation without concurrently traded prices by comparing observed American option prices to theoretical European option prices. A valid criticism of this methodology is that it assumes that the theoretical model generates true option prices. Several recent studies avoid this weakness by measuring the early exercise premium directly by comparing prices of concurrently traded American and European options. While these direct empirical studies have generally been carefully crafted, there are several important microstructure issues that remain unexplored. For example, no previous study uses perfectly contemporaneous quotes to measure the early exercise premium. The purpose of this study is to examine the effects of differential liquidity, non-contemporaneous quote observations, and the use of transaction prices on the direct empirical measurement of early exercise premiums.[1]

We examine a unique time period in the history of Standard and Poor's 500 index options. The Chicago Board Options Exchange listed European-style and American-style options on the Standard and Poor's 500 Index from April 2, 1986 through June 20, 1986. This dataset allows a matched-pair sample of intradaily quotes for otherwise identical American and European options. We match near-the-money American option quotes with the most

[1] The early investigations employing a theoretical model to generate European option prices on equities include Whaley (1982), Geske and Roll (1984), Blomeyer and Johnson (1988). Studies that essentially rely on observed market prices include Zivney (1991), Dawson (1994), Lee and Nayer (1996), and McMurray and Yadav (1996).

nearly contemporaneous, otherwise identical, European option quote. In this unique sample, the bid-ask spread for the American options is twice as large as the bid-ask spread for the European options. We find that this liquidity differential and non-contemporaneous quotes contaminate direct measures of the early exercise premium. If the liquidity and non-contemporaneous effects are ignored, the mean measured early exercise premium for *puts* is smaller than the mean theoretical early exercise premium. If the liquidity and non-contemporaneous effects are accounted for, the mean measured early exercise premium for *calls* is larger than the mean theoretical early exercise premium.

As reported in other studies, we find a larger early exercise premium for puts than for calls. However, even after the liquidity adjustments, we find the mean early exercise premium is 2.1% for calls and 4% for puts. These estimated early exercise premiums are smaller than those reported by Zivney (1991), Swindler and Zivney (1992), and Sung (1995). In our study, we find that the early exercise premium for both near-the-money calls and puts is significantly different from zero. Using simulated American prices from Barone-Adesi and Whaley (1987) and Harvey and Whaley (1992) as a benchmark, our results are consistent for puts but inconsistent for calls.[2]

The paper proceeds as follows. In the next section, we outline the possible sources of contamination when measuring the early exercise premium. Following a discussion of the unique dataset used in this study, we present evidence of how the sources of contamination affect the measurement of the early exercise premium. In Section 4, we present regression results designed to measure early exercise premiums in dollar levels and percentages. In Section 5 we focus on the "errors-in-variable" problem that arises when trade prices can occur anywhere inside (or occasionally outside) the prevailing bid-ask spread. In Section 5

[2]Using data for American call options on S&P 500 futures and European call options on the S&P 500 index, Lee and Nayer (1996) report a similar asymmetric empirical finding.

we also present evidence that traders must be able to trade inside the bid-ask spread if they are to profit from apparent arbitrage opportunities. Section 6 summarizes.

1 Previous Direct Empirical Measurement Studies

To avoid the joint hypothesis problem of using an option pricing model to calculate an early exercise premium, Zivney (1991) uses the put-call parity relationship to estimate early exercise premiums. Zivney argues that since the put-call parity relationship holds exactly for European options, deviations from put-call parity using American option prices can be attributable to an early exercise premium. Zivney (1991) suggests that the early exercise premium is sizable. Zivney estimates that the early exercise premium for Standard and Poor's 100 index options is 3.5 percent for calls and 10 percent for puts. Zivney was unable to measure the early exercise premium directly because American and European options do not trade concurrently on the Standard and Poor's 100 index. In addition, as documented by Kamara and Miller (1995), deviations from put-call parity could also reflect liquidity risk. Thus, it is possible that the early exercise premiums reported by Zivney also contain liquidity premiums.

Using data for American call options on S&P 500 *futures* and European call options on the S&P 500 index, Swindler and Zivney (1992) report an early exercise premium of about 4%. Examining put options on individual stocks, Sung (1995) reports a median early exercise premium of 8.7%. Jorion and Stoughton (1989a) report a 1 to 2% early exercise premium in foreign currency options. For international equity index markets, McMurray and Yadav (1996) report significant early exercise premiums in FTSE-100 stock index options. McMurray and Yadav also find observed early exercise premiums for puts and calls exceed theoretical premiums predicted by the binomial option pricing model. Lee and Nayer (1996) also use data for American call options on S&P 500 futures and European call options on the S&P 500 index.

There are several empirical problems that could lead to a miscalculation of the size of early exercise premium. For example, the use of end-of-day data [Zivney (1991)] introduces errors because the reported end-of-day data are generally non-contemporaneous transactions. Dawson (1994) and McMurray and Yadav (1996) address these problems by using intradaily American and European option data for the FTSE-100 stock index to estimate the early exercise premium. An inherent problem in the FTSE-100 data is that concurrent prices for American and European options do not really exist because there is always a 25 index point difference in the exercise price of otherwise equivalent American and European options.[3]

While they use intradaily data, Lee and Nayer (1996) use transaction prices. The use of transaction prices can impair the measurement of the early exercise premium through 'bid-ask bounce.' That is, one does not know whether the transaction occurred at the bid, the ask, or somewhere in between. Given the size of the early exercise premium relative to prevailing bid-ask spreads, this is an important consideration. We show that the use of transaction prices introduces significant errors into the measurement of early exercise premiums. Because this bias increases with the bid-ask spread, liquidity differences reflected in the bid-ask spreads could bias measurements of early exercise premiums. The use of quotes avoids potential early exercise premium measurement errors caused by non-contemporaneous trades and also captures any liquidity differentials reflected by the bid-ask spread.

While the McMurray and Yadav (1996) and Lee and Nayer (1996) studies both acknowledge the importance of contemporaneous intradaily prices by their sample construction, neither study attempts to align European and American quotes precisely. The con-

[3]This results because the American option prices on the FTSE-100 index are always divisible by 50. The European options are divisible by 25–but not by 50. Thus, exercise prices between otherwise identical American and European options will always differ by 25 index points.

tribution of this study is that it is the first to analyze the effects of differential liquidity, non-contemporaneous quotes and the use of transaction prices on the direct empirical measurement of the early exercise premium. We show that the failure to incorporate these microstructure effects can result in severe mismeasurement.

2 American and European Option Data

In an attempt to boost trading activity in options on the Standard and Poor's 500 index, the Chicago Board Options Exchange introduced the European-style SPX option on April 2, 1986. On that date, trading in the American-style SPQ option did not cease. Instead, the existing April, May, June, September, and December SPQ options were allowed to expire naturally. Trading activity in the American option was such, however, that the only expiration month that had any volume was the June 1986 contract. After the June expiration, trading ceased for the remaining American option contracts. Thus, the time period from April 2, 1986 through June 20, 1986 is unique in that there were European and American options trading concurrently on the Standard and Poor's 500 index.[4]

An analysis of data from CBOE tapes reveals that there were a total of 1,312 bid and ask quotes for SPQ calls and puts during the April through June time period. Most of these, 993, were quotes for the June SPQ contract with strike prices within ±10% of the index level. For each of these intradaily observations for the June contract, the data tape was searched for the closest SPX quote to form a pair of option quotes that differed *only* in the exercise feature. As shown in Figure 1, it is possible that the closest SPX quote could have occurred before or after the timestamp of the SPQ quote.

[4]During the period from April 2, 1986 through June 20, 1986, there were only 34 trades with a total volume of 298 contracts for put and calls combined for the American SPQ option. Currently, the European SPX option ranks second in volume and first in open interest for exchange listed options.

These matched pairs were examined for obvious data errors such as a missing bid or ask quote or instant arbitrage situations where the SPX bid is less than the SPQ ask. The quality of the matches is enhanced by ensuring that the difference between the midpoint of the American option quote and the European option quote is less than $3, the observed times are less than 20 minutes apart, and selecting options with prices greater than $0.50. Sheikh and Ronn (1992) document that there could have been some problems with the CBOE data during this time period. Thus, the observations for the first hour of trading (i.e., before 9:30:00) were removed. After employing these screens, our sample consists of 408 matched call and 251 matched put observations.

3 Measuring the Early Exercise Premium

3.1 Observed

Panel A of Table 1 reports the size of the early exercise premium using matched-pairs of intradaily American option quotes and their closest European option quote. Using bid-ask midpoints, the average size of the early exercise premium is $0.11 for calls and $0.04 for puts. Given the average midpoint of the call and put option quote, the early exercise premium is 1% for calls and 0.8% for puts.

Theoretically, if the American and European options have the same bid-ask spread, the same early exercise measurement would result using either bids or asks. However, in our sample, the bid-ask spread for the American option is twice that of the European option. This bid-ask spread differential is consistent with the American option being less liquid than the European option. As shown in Panel A of Table 1, the bid-ask spread differential is asymmetric in that the early exercise premium is negative, on average, when bid prices are compared but the early exercise premium is positive, on average, when ask prices are compared.

3.2 Liquidity and Non-Contemporaneous Adjustments

As shown in Figure 2, an early exercise premium should appear on both sides of the bid-ask spread because market participants should be willing to pay more and should demand more for an American option than a European option. However, the liquidity of the American options in the sample is such that the mean American SPQ bid price is *less* than the mean European SPX bid price. As a liquidity adjustment, we impose the observed American (and less liquid) bid-ask spread on its European match. We do this for each observation by subtracting the size of the American bid-ask spread from the European ask to construct a liquidity-adjusted European bid. Differences between the midpoint of the observed SPQ bid-ask spread and the midpoint of this liquidity-adjusted European bid-ask spread are one estimate we report for the early exercise premium.

The notation in Figure 1 shows how we generate a theoretically contemporaneous European option quote at the time of the observed American option quote. First, we calculate a Black-Scholes implied volatility for each match pair using the observed European ask and the liquidity-adjusted European bid at time O_{t+1}. Then, this implied volatility is used to calculate liquidity-adjusted theoretical European bid and ask prices at the time of the American option quote, O_t, by using the Black-Scholes (1973) model and the S&P 500 index level implied in S&P 500 futures at the time of the American SPQ quote. Differences between the observed SPQ ask and this contemporaneous theoretical European ask are reported as making a contemporaneous adjustment only. Differences between the midpoint of the observed SPQ bid-ask spread and the midpoint of this liquidity-adjusted contemporaneous European bid-ask spread are reported as liquidity-adjusted contemporaneous early exercise premiums.

We attempt to measure this liquidity-adjusted contemporaneous European bid-ask spread price as precisely as possible because of the well-known pricing biases of the Black-Scholes model. Studies by Black (1975), MacBeth and Merville (1979), and Rubinstein (1985), among others, conclude that the Black-Scholes model is accurate for near-the-money options [Corrado and Miller (1996) review this issue in depth]. Thus, pricing biases of the Black-Scholes model are not a significant worry in this study because the sample consists of near-the-money options only (i.e., options with a strike within ±10% of the index level).

The riskless rate we use in this study is the rate on the Treasury bill that expires two days before the June option expiration. We adjusted for dividends using Black's (1975) method of subtracting the present value of all dividends to be received before option expiration from the value of the index. Based on Figlewski's (1984) findings that the dividend uncertainty for the S&P 500 is insignificant, dividends are assumed known with certainty. An exact, published, daily dividend series for the S&P 500 index does not exist for each day in the sample but one was estimated by Kamara and Miller (1995) as follows.[5]

A monthly file of the stocks in the S&P 500 index is created from the *500 Information Bulletin* published by Standard and Poor's. Then, data for ex-dividend dates, shares outstanding, and cash dividend amounts for each stock in the index is extracted from the CRSP tapes. Dividends in terms of S&P 500 index points for each trading day is then calculated and then discounted using the appropriate Treasury bill rate. Finally, to avoid any potential "staleness" in the cash index as documented by Chung (1991), we calculate a theoretical cash index level at the time of the American quote by using the prevailing S&P 500 futures price and the cash-and-carry relationship for known discrete dividends:

[5]Harvey and Whaley (1992) independently used a similar approach to calculate an S&P 100 (OEX) dividend series.

$$S_t = e^{-r(T-t)} F_t + e^{-r(T-t)} \sum_{i=1}^{n} D_i e^{r(T-t)} \quad (1)$$

where S_t is the theoretical cash index level, F_t is the observed futures price, and D_i is the discrete daily dividend in index points.

Panel B of Table 1 reports the size of the early exercise premium using matched-pairs of intradaily American option quotes and their matched European option quotes with either a liquidity adjustment, a contemporaneous adjustment or both. Making the liquidity adjustment, the average size of the early exercise premium is $0.26 for calls and $0.22 for puts. Given the average midpoint of the call and put option quote, the early exercise premium percentage is 2.3% for calls and 3.8% for puts. These estimates are significantly larger than the mean theoretical early exercise premium in the sample of $0.07 (0.54%) for calls. For puts, the liquidity adjustment results in early exercise premiums that are similar to the mean theoretical early exercise premiums of $0.19 (3.3%). The theoretical early exercise premium is calculated for each observation using the Barone-Adessi and Whaley (1987) algorithm for American options and the *observed* midpoint of the European option bid-ask spread. Inputs into the algorithm are the index level implied by S&P 500 futures at the time of the European quote, volatility implied by the European options, strike price, days to maturity, dividend yield, and the riskless interest rate. The mean theoretical early exercise premium is $0.06 (0.54%) for calls and $0.19 (3.3%) for puts.

A striking result of making these two adjustments is that it appears that they are nearly substitutes. That is, there does not appear to be a large gain from making both the liquidity and contemporaneous adjustments. As reported in Panel B of Table 1, the early exercise premium for puts and calls that results from making either a liquidity adjustment only or a contemporaneous adjustment is similar to the early exercise premium for puts and calls that results from making both a liquidity and a contemporaneous adjustment. In all cases, the early exercise premiums measured for puts are about the same as the theoretical early exercise premiums. For calls, however, the adjustments result in an early exercise premium that is significantly larger than the theoretical value.

4 Tests for the Size of Early Exercise Premiums

4.1 Theoretical Model

Free disposal dictates that the right to exercise an American option must have a non-negative value. This implies the value of an American option must be equal to the value of an identical European option plus the early exercise premium. This proposition can be tested with the following regression:

$$\text{American Option Price}_t = \alpha + \beta(\text{Price of an Identical European Option})_t + \eta_t. \tag{2}$$

If American options are priced according to this model, one should be able to reject the joint null that $\beta = 1$, and $\alpha = 0$. If the joint null is rejected, and the null that $\beta = 1$ cannot be rejected, then the intercept term would be interpreted as the early exercise premium. In addition, such a rejection would indirectly validate the method of generating a matching European bid-ask spread as described above.

Note that the true input to the right-hand side of equation (2) is unavailable. The truly contemporaneous observed European option quote must be estimated from observed data. Thus, the estimation is subject to "errors-in-variable" bias unless instrumental variable estimation is used. Therefore, equation (2) will be estimated using Two-Stage Least Squares for both the 'observed' matched pairs and the 'generated' matched pairs. Instruments used in the Two-Stage Least Squares regression for the 'observed' matched pairs are the time difference between the American and European option quotes, implied volatility from the European options, days to expiry, and moneyness. Instruments used in the 'generated' matched pairs are the observed European price, implied volatility from the European options, days to expiry, and moneyness.[6]

4.2 Liquidity and Non-Contemporaneous Effects on the Measurement of the Early Exercise Premium

4.2.1 Observed

Although some previous research has used intradaily data in the investigation of early exercise premiums, no previous study has examined the effects of timing differences of quote observations. In Table 2, four sets of results are presented. Panel A displays results from estimating equation (2) using the observed matched pairs. For both puts and calls, the joint null that the intercept is zero and the slope is one is rejected for all observations and for those observations for quotes less than ten minutes apart. For calls, the rejection stems from the fact that the intercept is statistically different from zero. For puts, the rejection stems from the fact that the slope is statistically different from one.

In terms of the economic significance of the call early exercise premiums, the estimates from the *intercepts* are \$0.085 and \$0.105, respectively. This is approximately a 1% early exercise premium. For the puts, the *slope* coefficients result in an early exercise premium of about \$0.05 and \$0.08, respectively. This is approximately a 0.5% early exercise premium. The size of these early exercise premiums underscores the importance of accounting for all

[6] Results from Ordinary Least Squares estimation are nearly indistinguishable. Details are available on request.

possible imperfections. If some imperfections are ignored, the measurement of the true early exercise premium can be greatly distorted.

Although there are no observations in the sample with a timestamp difference of more than 20 minutes, the difference in the timestamps of the American and European quotes has a significant impact. For calls and puts, when the observed quotes are more than 10 minutes apart, no evidence of an early exercise premium is found. The joint null that the slope is one and the intercept is zero is not rejected. In both cases, the slope coefficient is not statistically different from one and the intercept is not statistically different from zero.

Theoretically, there is no hypothesis predicting this result, other than the econometric "errors-in-variables" problem leading to downwardly biased coefficients. It is possible that a positive, negative, or zero early exercise premium could have been observed when the quote observations are more than 10 minutes apart. However, the sample result does underscore the importance of observing contemporaneous quotes.

4.2.2 Liquidity and Non-Contemporaneous Adjustments

Adjusting the data for differences in liquidity or making a non-contemporaneous adjustment has a significant impact on the estimated early exercise premiums. Panels B of Table 2 displays results from estimating equation (2) using the liquidity-adjusted matched pairs. For both puts and calls, the joint null that the intercept is zero and the slope is one is rejected in all cases. In addition, significantly larger early exercise premiums are found. For calls and puts, the estimated early exercise premium ranges from $0.21 to $0.30. Compared to a theoretical early exercise premium based on the Barone-Adessi and Whaley (1987) algorithm reported in Table 1, the estimated mean early exercise premiums for calls (about 2.7%) are much larger than the mean theoretical premiums (0.5%). For puts, the estimated mean early exercise premium is about 5% but the mean theoretical early exercise premium for puts is only 2.9%.

Panels C of Table 2 displays results from estimating equation (2) making the non-contemporaneous adjustment. Panel D displays the results from making both the liquidity and non-contemporaneous adjustments. In general, the results are similar to the results in Panel B. Early exercise premiums for calls are estimated to be about 1.5 to 2.5 percent and early exercise premiums for puts are estimated to be about 3.5 to 4.0 percent.

The early exercise premiums reported above are estimated at the mean where the option prices are in levels. By construction, such an estimation technique assumes that the early exercise premium is constant dollar amount. For comparison, Table 3 presents a set of estimated early exercise premiums at the mean where the option prices are in logs. In this case, under the null hypothesis of a slope coefficient equal to one, the regression intercept represents a constant percentage early exercise premium. The potential advantage of the log specification is that it allows the dollar value of the early exercise premium to vary with the level of the option price. When adjustments are made for liquidity and non-contemporaneous prices, the estimated early exercise premiums for calls range from 1.3 to 3.5 percent. For puts, the estimated early exercise premiums range from 5.3 to 6.0 percent.

4.2.3 Comparison to Prior Studies

Whether the early exercise premium is measured in levels or logs, our estimates of early exercise premiums for index options are smaller than those reported by previous studies. For calls, we estimate an early exercise premium of 1.3 to 3.5 percent. Zivney (1991) reports an estimate of 3.5 percent and Swindler and Zivney (1992) find an early exercise premium of about 4 percent. For puts, we estimate an early exercise premium ranging from 3.5 to 6 percent. Zivney (1991) reports an early exercise premium estimate of about 10 percent while Sung (1995) finds a median early exercise premium of 8.7 percent for equity put options.

A careful measurement of the early exercise premium is important when one is studying the rational early exercise of index options. Recent empirical studies of the rationality of early exercise for the S&P 100 index options include French and Maberly (1992) and Diz and Finucane (1993). As discussed thoroughly by Diz and Finucane (1993), rational early exercise of call options on stock indexes can occur if the annualized dividend yield received over the remaining life of the option exceeds the annualized risk-free rate of interest. Rational exercise of call options on stock indexes can also occur if there is a cluster of discrete dividends on the constituent stocks comprising the index. Early exercise for put options on stock indexes is desirable if the profit from exercising the put is sufficiently large so that the interest that could be earned by investing the profit now exceeds the possibility of an even greater profit from continuing to hold the put.

Rational early exercise of stock index options can also stem from the so-called "wildcard" option. The wildcard option arises because the proceeds from exercise are based on the difference between the exercise price of the option and the index level at the close of the NYSE. Because the index option market remains open after the close of the NYSE, option holders have an extra fifteen minutes to decide whether to exercise the option. During this time, news arrivals affecting the underlying index can make early exercise optimal.[7]

4.3 Early Exercise Premium Sensitivity to Option Pricing Factors

Jorion and Stoughton (1989b) derive comparative statics concerning the sensitivity of the early exercise premium in currency options to various parameter inputs. Under the usual Black-Scholes assumptions, Jorion and Stoughton propose that early exercise premiums for

[7]It is also possible that early exercise is rational if it is cheaper to exercise the option than it is to sell the option and take a position in the underlying asset.

calls and puts should increase as moneyness increases and as days to expiry increases. For currency options, both the domestic and foreign interest rates have an effect. For equity options under the usual Black-Scholes assumptions, an increase in interest rates increases call prices but decreases put prices.

Jorion and Stoughton (1989a), Zivney (1991), and Sung (1995) conduct regression tests of the sensitivities of the early exercise option to various input levels. Jorion and Stoughton find that early exercise premiums for foreign currency call options are positively affected by moneyness, the foreign interest rate (as predicted) and volatility. They report no significant regressors for puts. Sung (1995) reports the early exercise premium for equity put options is positively related to moneyness and volatility. Jorion and Stoughton report $R^{2's}$ of 0.048 for calls and 0.007 for puts and Sung reports an R^2 of 0.126 for puts.

Zivney (1991) concludes that the value of the estimated early exercise premium in S&P 100 index options varies like a well-behaved option because the early exercise premium increases as moneyness, days to expiry, and the riskless interest rate increases. Zivney finds a significant relationship between positive early exercise premiums and the factors as he reports $R^{2's}$ of 0.330 for puts and 0.512 for calls.

In our sample, the overall relationship between the early exercise premium and the factors is similar to the relationship reported by Jorion and Stoughton (1989a). The OLS $R^{2's}$ are about 0.03 for calls and puts when the size of the early exercise premium is regressed on days to expiration, moneyness, and the riskless interest rate. Consistent with the predicted sign of the comparative statics, the early exercise premium for calls is positively related to moneyness and the riskless interest rate and, for puts, the early exercise premium is positively related to moneyness and days to maturity.

5 Simulations of the Effect of Using Trade Prices to Measure Early Exercise Premiums

Here we focus on the "errors-in-variable" problem that occurs when trade prices can happen anywhere inside (or occasionally outside) the prevailing bid-ask spread. Otherwise identical American and European options that transact simultaneously will not be perfect matches if they trade at different points within their respective bid-ask spreads. This form of "bid-ask bounce" introduces errors into attempts to measure the true early exercise premium from trade prices. We run a Monte Carlo simulation of the average early exercise premiums calculated from samples of 300 observations (roughly matching our sample size). The "bid-ask bounce" problem in trade prices results in a loss of precision. In turn, this leads to fairly wide 95% confidence intervals and skewed distributions about the true early exercise premium.

In each simulation run, we draw 300 lognormal European option prices with a mean and a standard deviation of \$11.[8]From this "true" price, we draw a "trade" price from a distribution within the assumed bid-ask spread. We calibrated a "narrow" bid-ask spread to our sample average of 3.58% for European quotes and a "wide" bid-ask spread to the sample average of 7.3% for American quotes. The true American price is assumed to be the true European price plus 3.0%, an assumed true early exercise premium. A trade price for the American is then drawn from a distribution within the assumed bid-ask spread, either narrow or wide. For each sample of 300 observations of simulated European and American trading prices, we calculated a sample average early exercise premium in three different ways. The first is simply to take the mean of the observed early exercise premia, as

[8]In our sample, the average level of the S&P 500 index is 242, the average implied volatility is 15.7% and the average risk-free rate is 6.12%. Using these inputs, a strike price of 235 and 79 days to expiration, the Black-Scholes call formula yields a European option price of \$11.02. The standard deviation of the observed call prices in our sample is \$6.53. Note further that the lognormal price is always positive.

measured by $AMER/EURO - 1$. We call this approach the "data" method. The other two methods consist of replacing the observed American trading prices with the fitted values from regressions of the American trading prices on European trading prices, where the regressions were run in levels and logs. This process was repeated 1000 times, leading to an empirical distribution of the sample average early exercise premium which could be compared to the true value of 3%. We derive empirical 95% confidence intervals for the calculated early exercise premium and for the regression coefficients.

Panel A of Table 4 presents existing empirical evidence on the distribution of options trading prices within prevailing bid-ask spreads. The empirical distributions shown are Vijh (1990), Hemler and Miller (1996) and Miller (1992). Vijh studies CBOE equity options during March and April 1995. Hemler and Miller examine S&P 500 Index options (SPX) in September and early October 1987 while Miller examines SPX options during January, February, and March 1989. Because the distributions reported by Vijh and Hemler and Miller are so similar, only results from the Vijh distribution are compared to results generated by the more disperse distribution in Miller (1992). A significant difference between the Vijh and Miller results is the percentage of trades that fall outside the bid-ask spread. Based on the results in Miller (1992), we assume that when a trade occurs higher than the ask price, it occurs at a level equal to the ask price plus 10%. When a trade occurs lower than the bid price, it occurs at a level equal to the bid price minus 10%.[9]

Table 4 also summarizes the empirical distributions of the regression coefficients. Panel B of Table 4 compares, for the Vijh distribution, the estimated regression coefficients and the true regression coefficients. For the log regression, the true values are .03 for the intercept

[9]Interestingly, in July 1989, the Chicago Board Options Exchange instituted the "10-Up Rule," i.e., Rule 8.51 of the *CBOE Constitution and Rules.* This rule states that at all times other than during the opening rotation, all market makers at a trading stations are required to transact at least 10 contracts at or within the prevailing bid-ask spread. For details on Rule 8.51, see Chicago Board Options Exchange (1996).

and 1.0 for the slope. The empirical distributions have respective means of .0285 and .999. For the levels regression, the true values are zero for the intercept and 1.03 for the slope. The simulated empirical distributions have means of .019 and 1.026. In both cases the 95% confidence intervals displayed in Panel A of Table 4 contain the true parameter values.

We also consider the case where the bid-ask bounce takes place under the more disperse Miller (1992) distribution. Panel C of Table 4 show that for all combinations of wide and narrow bid-ask spreads on the American and European options, the mean early exercise premium and its 95% confidence interval in the log regression is always shifted down from that of the data. Although the bias is not terribly large, it does skew the distribution to the left of the true 3% early exercise premium. Figure 3 shows a histogram of the 1000 draws corresponding to the early exercise premiums from the log regression in Panel B of Table 4. The distribution looks fairly symmetric, but it is centered at about 2.9% instead of 3%. Consequently 642 of the 1000 points lie to the left of the true value. The levels regression, on the other hand, is much less reliable, yielding a 95% confidence interval for the average early exercise premium between roughly zero and 6.9%.

Using the Vijh (1990) distribution, the "narrow" bid-ask spread for European options and the "wide" bid-ask spread for American options, we report results in Panel D of Table 4 showing that in the generated data the 95% confidence interval for the calculated early exercise premium from a sample of 300 observations is (.0226,.0337) with a mean of .0282. Calculated early exercise premia from the regression methods show that the log regression provides a tighter 95% confidence interval than the levels regression: (.0216,.0326) versus (.0050,.0540) for OLS. Thus, the log regression does much better than the levels regression at recovering the distribution of early exercise premia actually found in the simulated trades data. The means of the empirical distributions of early exercise premia are .0271 and .0293 for the log and levels regressions, respectively. Notice that errors-in-variable bias is downward and shifts the log regression confidence interval and mean below that found in the data. The levels regression has a second source of bias because its residuals are non-spherical, lognormal variables–making the overall direction of bias difficult to assess.

The biggest question we raise about using trade price data concerns the dispersion of the data themselves from the true underlying early exercise premium. Taking Panel B of Table 4 as an example, we see that in a random sample of 300 observations, the 95% confidence interval for the sample average early exercise premium contains early exercise premiums that range from 32% too small to 31% too large, relative to the true 3% early exercise premium. Once one adds additional imperfections, such as lack of contemporaneity, it becomes increasingly difficult to place much confidence in the average early exercise premium from a sample of 300 trade price observations. These simulations are strong evidence supporting the use of quotes, rather than trades, to measure early exercise premiums.

5.1 Implications for Arbitrage Trading Strategies

Free disposal dictates that the value of an American option must be equal to the value of an identical European option plus a premium for the right to exercise the American option before expiration. Empirically, Lee and Nayer (1996) and McMurray and Yadav (1996) report instances of *negative* early exercise premiums, i.e., cases where the American option is selling for less than an identical European option. McMurray and Yadav (1996) find a negative early exercise premium in 32% of their call sample and 17% of their put sample while Lee and Nayer (1996) report negative early exercise premiums occur in 47% of their call sample and 58% of their put sample.[10]

Lee and Nayer (1996) report that about 22% and 24% of the mispriced observations of

[10] In the McMurray and Yadav (1996) sample, the American option and the European option do not have identical exercise prices. Thus, as they point out, "it is not possible to adopt a totally risk-free arbitrage strategy to exploit the anomaly."

call options and put options, respectively, provide profitable arbitrage opportunities even in the presence of realistic retail transaction costs. However, Lee and Nayer (1996) must simulate a bid-ask spread from their sample of trade prices to conduct their arbitrage tests. In our study, observed bid-ask spreads are directly available to conduct arbitrage tests when an American option price is less than a European option price.

Using the original 993 combined raw matched pairs to identify the time of the American quote, we scan the CBOE tape for two matching European quotes: the closest one before and the closest one after the American quote. In some cases, there is no European quote before the American quote. These observations are discarded as well as observations with quotes equal zero, days to expiration less than 5, and an absolute value between the midpoint of the quotes greater than \$3.00. This results in a sample of 467 call observations and 346 put observations.[11]

We conduct the following simulations. At the time of each observed American quote, we 1) compare the observed American midpoint to the prevailing European midpoint and 2) compare the observed American ask to the prevailing European bid. In addition, we calculate a Black-Scholes European option quote using data from the prevailing quotes to calculate an implied standard deviation and the cash index level at the time of the American quote. Then, we 3) compare the observed American midpoint to the theoretical European midpoint and 4) compare the observed American ask to the theoretical European bid. In each of the four comparisons, if the American price is less than the European price, we call this an 'apparent arbitrage.' We assume a wholesale transaction fee of \$5 per contract and also assume traders will initiate an arbitrage trade only if the price differential exceeds this fee.

[11]Because Sheikh and Ronn (1992) document that there could have been some problems with the CBOE data during this time period, we also examine data sets where observations for the first hour of trading (i.e., before 9:30:00am) were removed. The sample size here is 217 calls and 134 puts.

Then, we assume traders "leg-on" the apparent arbitrage trade in two ways. In the first way, we assume that the trader receives price improvement on both sides of the trade. That is, the trader buys the American option at the midpoint of the current, observed bid-ask spread and sells the European option at the midpoint of the next *observed* European quote. In the second way, we assume the trader receives no price improvement. That is, the trader buys the American option at the ask price of the current, observed quote and sells the European option at the bid price of the next *observed* European quote.

Table 5 summarizes the results of these simulations. When traders use the midpoint screens, i.e., screens 1 or 3, apparent arbitrage opportunities are signaled roughly one-third of the time. If it is assumed that traders can trade at the midpoint of the prevailing American quote and the midpoint of the next European quote, traders would realize an average profit ranging from $11 to $27 per contract. If traders pay the prevailing American ask and receive the next European bid, traders would realize an average loss ranging from $32 to $42 per contract.

If traders use the screens that impose bid-ask spreads, i.e., screens 2 or 4, apparent arbitrage opportunities are signaled only 2 to 8 percent of the time. If it is assumed that traders can trade at the midpoint of the prevailing American quote and the midpoint of the next European quote, traders would realize an average profit ranging from $52 to $133 per contract. If traders pay the prevailing American ask and receive the next European bid, traders would realize results ranging from an average loss of $16 to an average profit of $73 per contract.

The results of these simulations highlight the importance of the assumptions that the American quote is good until updated [Hemler and Miller (1996)] and of the assumed size of the bid-ask spread used to test option market efficiency [Phillips and Smith (1980)]. If the American quote is not good until updated, there is no way to conduct an arbitrage simulation using our data because of the infrequent observations of American quotes. When trades occur at the relevant bid and ask prices, traders in our simulations lost money, on average, when they acted on signals based on spread midpoints. Traders generally profited when they used arbitrage signals based on relevant quotes–even in the cases where trades are executed at the relevant bid and ask prices.

6 Summary and Implications

The first investigations into the size of the early exercise premium attempted the valuation without concurrently traded prices by comparing observed American option prices to theoretical European option prices. A valid criticism of this methodology is that it assumes that the theoretical model generates true option prices. Several recent studies avoid this weakness by measuring the early exercise premium directly by comparing prices of concurrently traded American and European options. While these direct empirical studies have generally been carefully crafted, no previous study has measured the early exercise premium using contemporaneous quotes. In addition, there are several important microstructure issues that remain unexplored in the early exercise premium literature.

We analyze matched pairs of intradaily American and European option prices on the Standard and Poor's 500 index during a unique time period at the Chicago Board Options Exchange. From April 2, 1986 through June 20, 1986 American and European options traded concurrently on the same underlying asset. During this time period, there was a significant liquidity difference between the American and European options. In our sample consisting of 408 matched call observations and 251 matched put observations, the bid-ask spread for the American options is twice as large as the bid-ask spread for the European options. We find that this liquidity differential and the non-contemporaneously observed quotes affect the measurement of the early exercise premium. If the liquidity and non-contemporaneous effects are ignored, the mean measured early exercise premium for *puts* is smaller than the mean theoretical early exercise premium. If the liquidity and non-contemporaneous effects are accounted for, the mean measured early exercise premium for *calls* is larger than the mean theoretical early exercise premium.

This study is the first to analyze the effects of differential liquidity, non-contemporaneous quotes and the use of trade prices on the direct empirical measurement of the early exercise premium. We show that the failure to incorporate these important market microstructure effects into the direct measurement of the early exercise premium can severely distort the measurement. In addition, we show how biased estimates of early exercise premiums result from using trade prices instead of quotes because a bias enters through an "errors-in-variables" problem when transactions can occur anywhere inside (or, occasionally outside) the prevailing bid-ask spread. This bias increases as the dispersion of the distribution of potential transaction prices increases. This bias results in a considerable loss of precision in 95% confidence intervals and standard errors.

As reported in previous studies, we find a larger early exercise premium for puts than for calls. However, after the liquidity and non-contemporaneous adjustments, we find the mean early exercise premium is 2.1% for calls and 4% for puts. These estimated early exercise premiums are smaller than those reported by Zivney (1991), Swindler and Zivney (1992), and Sung (1995). We find that the early exercise premium for both near-the-money calls and puts is significantly different from zero. Using the simulations by Barone-Adesi and Whaley (1987) and Harvey and Whaley (1992) as a benchmark, our results are consistent for puts but inconsistent for calls. One implication of this finding is that existing theoretical American call option pricing models should be modified to capture more aspects of the early exercise decision.

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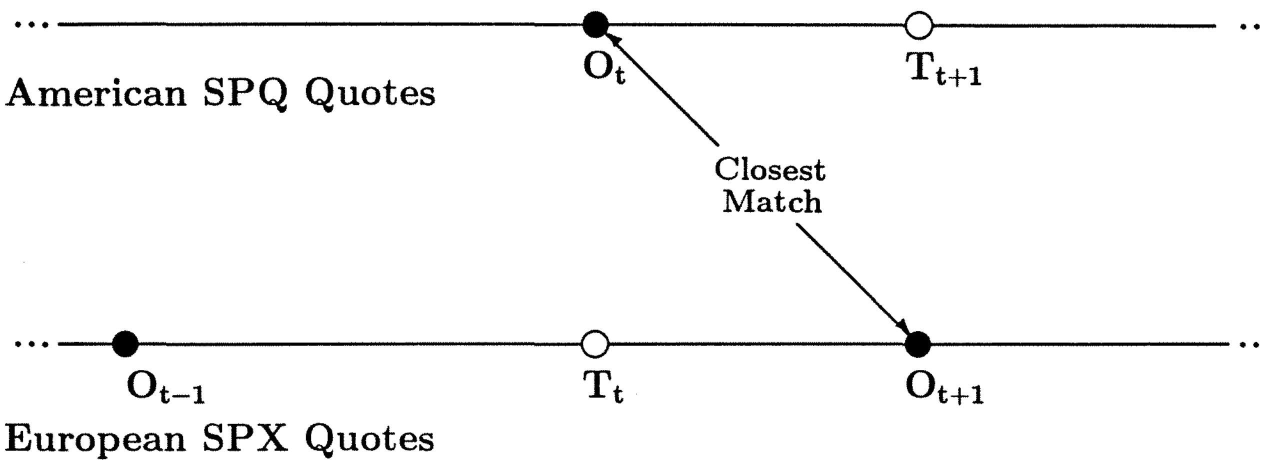

Figure 1. Matching the American and European Quotes. For each American option quote observation O_t, an otherwise matching European option quote observation, O_{t+1}, is selected based on its timestamp. A theoretical European option price at the time of the American quote, T_t, is generated using the Black-Scholes model. European implied standard deviation is from time O_{t+1} and the cash index used is the implied S&P 500 index level implied by t he S&P 500 futures price at time O_t. A theoretical American option price at the time of the matching European quote, T_{t+1}, is generated using the Barone-Adesi-Whaley algorithm. American implied standard deviation is from time O_t and the cash index used is the implied S&P 500 ind ex level implied by the S&P 500 futures price at time O_{t+1}.

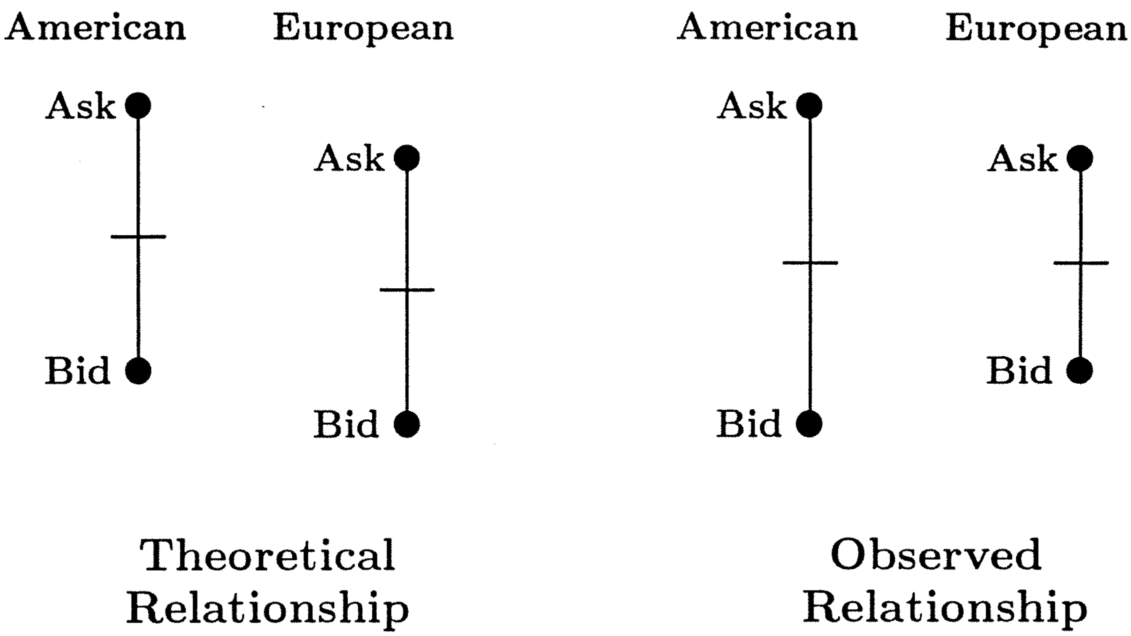

Figure 2. Theoretical and Observed Bid-Ask Spreads for American and European Options. An American option can never be worth less than a European option. The right to exercise early means that investors would be willing to pay more for, and expect to receive more from, an American option compared to an otherwise identical European opt ion.

Figure 3. The Distributions of Mean Early Exercise Premiums from the Generated Data, the Fitted Log Regression, and From the Fitted Level Regression

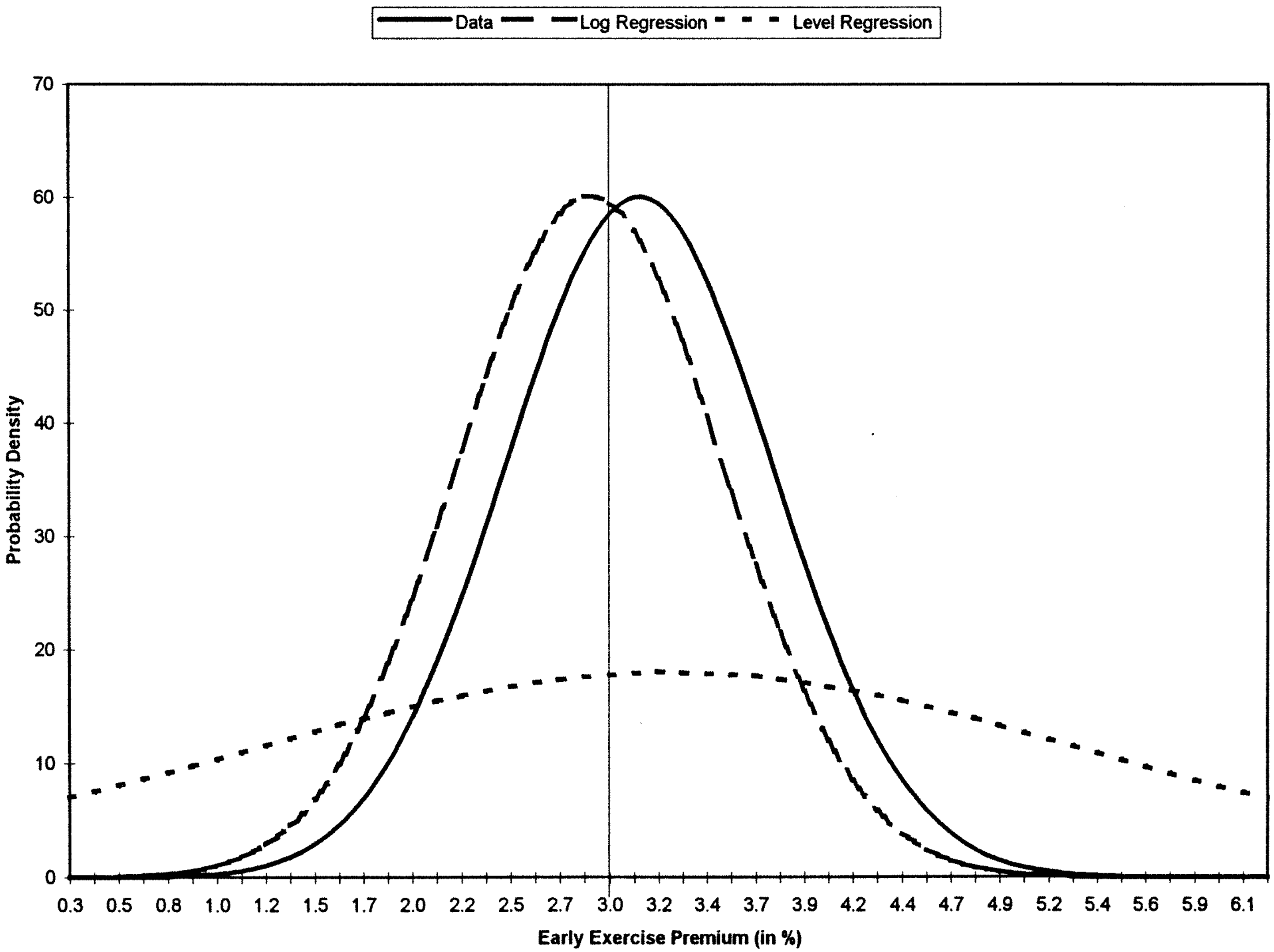

TABLE 1

Mean Observed Early Exercise Premiums, Mean Observed Bid-Ask Spreads by Component and Mean Liquidity-Adjusted; Contemporaneous; and Liquidity-Adjusted Contemporaneous Early Exercise Premiums. Intradaily call and put option quotes investigated are American-style (SPQ) and European-style (SPX) options on the Standard and Poor's 500 Cash Index traded at the Chicago Board Options Exchange from April 2, 1986 through June 20, 1986. The 'Observed' numbers use a matched-pair generated for each intradaily American option quote and its closest European option quote. The 'Liquidity-Adjusted' numbers impose the observed American bid-ask spread on its observed European match. This is equivalent to comparing the observed American ask to the observed European ask. The 'Contemporaneous' numbers compare the observed American ask to a theoretical European ask generated using the Black-Scholes model at the time of the observed American ask. The 'Liquidity-Adjusted Contemporaneous' numbers impose the observed American bid-ask spread on a theoretical European match generated using the Black-Scholes model at the time of the observed American quote using the observed European implied standard deviation as the volatility input. The sample consists of 408 call and 251 put observations. Numbers in parentheses are percentage early exercise premiums.

	SPQ-SPX Calls	SPQ-SPX Puts
Panel A. Observed and Theoretical Early Exercise Premiums		
Early-exercise premium using:		
Bid-ask midpoints	$0.065 (0.59%)	$0.019 (0.3%)
American Ask Minus European Ask	0.26 (2.3%)	0.22 (3.8%)
American Bid Minus European Bid	-0.13 (-1.2%)	-0.18 (-3.1%)
American-style (SPQ) bid-ask spread	$0.79	$0.72
European-style (SPX) bid-ask spread	0.40	0.32
Mean American option price (bid-ask midpoint)	$11.23	$5.84
Mean European option price (bid-ask midpoint)	11.17	5.82
Theoretical early exercise premium using the Barone-Adesi Whaley (1987) algorithm and the mean European option price	$0.06 (0.54%)	$0.19 (3.3%)
Panel B. Early Exercise Premiums by Making:		
A Liquidity Adjustment Only	$0.26 (2.3%)	$0.22 (3.8%)
A Non-Contemporaneous Adjustment Only	$0.21 (1.9%)	$0.23 (4.0%)
Both a Liquidity and Non-Contemporaneous Adjustment	$0.24 (2.1%)	$0.23 (4.0%)

TABLE 2

Estimated Two Stage Least Squares Regression Coefficients Using Option Prices in Levels. P-Values reported are from tests of the joint null hypothesis that the intercept equals zero and the slope coefficient equals one. Intradaily call and put option quotes investigated are American-style (SPQ) and European-style (SPX) options on the Standard and Poor's 500 Cash Index traded at the Chicago Board Options Exchange from April 2, 1986 through June 20, 1986. The 'Observed' Panel use a matched-pair generated for each intradaily American option quote and its closest European option quote. Instruments used here are the time difference between the American and European option quotes, implied volatility from the European options, days to expiry, and moneyness. The 'Liquidity-Adjusted Theoretical' Panel reports the results when the observed American bid-ask spread is imposed on a theoretical European match generated using the Black-Scholes model for the time of the observed American quote. Instruments used here are the observed European price, implied volatility from the European options, days to expiry, and moneyness. Within each panel, results are reported for the entire sample, instances when the quotes occurred within ten minutes of each other, and instances when the quotes were observed more than ten from each other. The $\bar{R}^2$ from all regressions exceeds 0.99. Standard errors are in parentheses. The 'Pct. EEP' column contains the percentage early exercise premium estimated at the mean when the option prices are in levels.

American Option Price $= \alpha + \beta$(Price of an Identical European Option) $+ \eta$. $H_0 : \alpha = 0$ and $\beta = 1$

	Calls					Puts				
	N	$\hat{\alpha}$	$\hat{\beta}$	Joint P-Value	Pct. EEP	N	$\hat{\alpha}$	$\hat{\beta}$	Joint P-Value	Pct. EEP
Panel A. Observed										
All Quotes	408	0.01 (.04)	1.005 (.003)	0.0004	0.6	251	-0.03 (.03)	1.01 (.004)	0.0277	0.3
Quotes < 10 Minutes Apart	306	0.02 (.04)	1.01 (.003)	0.0001	0.8	179	-0.03 (.03)	1.01 (.005)	0.0628	0.5
Quotes ≥ 10 Minutes Apart	102	-0.07 (.08)	1.01 (.006)	0.5606	0.1	72	-0.04 (.04)	1.01 (.006)	0.4127	0.2
Panel B. Liquidity Adjustment Only										
All Quotes	408	0.16 (.038)	1.01 (.003)	0.0001	2.3	251	0.16 (.03)	1.01 (.004)	0.0001	3.8
Quotes < 10 Minutes Apart	306	0.18 (.042)	1.01 (.004)	0.0001	2.7	179	0.15 (.04)	1.01 (.005)	0.0001	4.0
Quotes ≥ 10 Minutes Apart	102	0.04 (.083)	1.01 (.006)	0.0001	1.5	72	0.18 (.05)	1.004 (.007)	0.0001	3.6

	Calls					Puts				
	N	$\hat{\alpha}$	$\hat{\beta}$	Joint P-Value	Pct. EEP	N	$\hat{\alpha}$	$\hat{\beta}$	Joint P-Value	Pct. EEP
Panel C. Non-Contemporaneous Adjustment Only										
All Quotes	410	0.28 (.05)	0.99 (.004)	0.0001	1.9	254	0.17 (.03)	1.01 (.004)	0.0001	3.8
Quotes < 10 Minutes Apart	307	0.25 (.05)	1.00 (.004)	0.0001	2.5	181	0.17 (.03)	1.01 (.005)	0.0001	3.8
Quotes ≥ 10 Minutes Apart	103	0.33 (.12)	0.98 (.008)	0.0302	1.5	73	0.16 (.05)	1.01 (.008)	0.0001	4.1
Panel D. Liquidity and Non-Contemporaneous Adjustments										
All Quotes	408	0.21 (.04)	1.00 (.003)	0.0001	2.2	251	0.16 (.03)	1.01 (.004)	0.0001	4.0
Quotes < 10 Minutes Apart	306	0.21 (.04)	1.01 (.004)	0.0001	2.7	179	0.16 (.03)	1.01 (.005)	0.0001	4.0
Quotes ≥ 10 Minutes Apart	113	0.18 (.09)	1.00 (.006)	0.0085	1.9	96	0.17 (.05)	1.02 (.007)	0.0001	3.9

TABLE 3

Estimated Two Stage Least Squares Regression Coefficients Using Log Option Prices. P-Values reported are from tests of the joint null hypothesis that the intercept equals zero and the slope coefficient equals one. Intradaily call and put option quotes investigated are American-style (SPQ) and European-style (SPX) options on the Standard and Poor's 500 Cash Index traded at the Chicago Board Options Exchange from April 2, 1986 through June 20, 1986. The 'Observed' Panel use a matched-pair generated for each intradaily American option quote and its closest European option quote. Instruments used here are the time difference between the American and European option quotes, implied volatility from the European options, days to expiry, and moneyness. The 'Liquidity-Adjusted Theoretical' Panel reports the results when the observed American bid-ask spread is imposed on a theoretical European match generated using the Black-Scholes model for the time of the observed American quote. Instruments used here are the observed European price, implied volatility from the European options, days to expiry, and moneyness. Within each panel, results are reported for the entire sample, instances when the quotes occurred within ten minutes of each other, and instances when the quotes were observed more than ten from each other. The $\bar{R}^2$ from all regressions exceeds 0.99. Standard errors are in parentheses. The 'Pct. EEP' column contains the percentage early exercise premium estimated at the mean when the option prices are in logs.

Log American Option Price = $\alpha + \beta$(Log Price of Identical European Option) + η. $H_0 : \alpha = 0$ and $\beta = 1$

	Calls					Puts				
	N	$\hat{\alpha}$	$\hat{\beta}$	Joint P-Value	Pct. EEP	N	$\hat{\alpha}$	$\hat{\beta}$	Joint P-Value	Pct. EEP
Panel A. Observed										
All Quotes	408	-0.002 (.007)	1.003 (.003)	0.0285	0.5	251	-0.03 (.007)	1.02 (.004)	0.0005	-0.3
Quotes < 10 Minutes Apart	306	-0.004 (.008)	1.005 (.003)	0.0079	0.7	179	-0.03 (.008)	1.02 (.005)	0.0028	-0.3
Quotes ≥ 10 Minutes Apart	102	-0.0002 (.01)	1.00 (.005)	0.9573	-0.1	72	-0.018 (.01)	1.01 (.007)	0.2630	-0.4
Panel B. Liquidity Adjustment Only										
All Quotes	408	0.08 (.007)	0.98 (.003)	0.0001	3.1	251	0.11 (.01)	0.96 (.005)	0.0001	5.5
Quotes < 10 Minutes Apart	306	0.88 (.008)	0.98 (.004)	0.0001	3.6	179	0.10 (.009)	0.96 (.006)	0.0001	5.3
Quotes ≥ 10 Minutes Apart	102	0.059 (.015)	0.98 (.006)	0.0001	1.7	72	0.13 (.01)	0.95 (.008)	0.0001	5.8

	Calls					Puts				
	N	$\hat{\alpha}$	$\hat{\beta}$	Joint P-Value	Pct. EEP	N	$\hat{\alpha}$	$\hat{\beta}$	Joint P-Value	Pct. EEP
Panel C. Non-Contemporaneous Adjustment Only										
All Quotes	410	0.09	0.97	0.0001	2.7	254	0.11	0.96	0.0001	5.4
		(.008)	(.003)				(.007)	(.004)		
Quotes < 10 Minutes Apart	307	0.08	0.98	0.0001	3.2	181	0.11	0.96	0.0001	5.2
		(.009)	(.004)				(.008)	(.005)		
Quotes ≥ 10 Minutes Apart	103	0.09	0.97	0.0302	1.3	73	0.12	0.96	0.0001	5.6
		(.02)	(.007)				(.01)	(.009)		
Panel D. Liquidity and Non-Contemporaneous Adjustments										
All Quotes	408	0.08	0.98	0.0001	3.0	251	0.11	0.96	0.0001	5.6
		(.07)	(.003)				(.007)	(.004)		
Quotes < 10 Minutes Apart	306	0.09	0.98	0.0001	3.5	179	0.11	0.96	0.0001	5.5
		(.001)	(.004)				(.008)	(.005)		
Quotes ≥ 10 Minutes Apart	102	0.06	0.98	0.0001	1.4	72	0.13	0.95	0.0001	6.0
		(.01)	(.006)				(.01)	(.008)		

TABLE 4

The Effect of Using Trades to Measure Early Exercise Premiums in Call Options In the sample, the average level of the S&P 500 Index is 242, the average volatility is 15.7%, and the average risk-free rate is 6.12%. Using these inputs, a strike of 235 and 79 days to expiration, the Black-Scholes call formula yields a European option price of $11.02. Assuming a true early exercise premium of 2.4%, a European option bid-ask spread of 3%, and an American option bid-ask spread of 7%, the following simulation was performed. A sample of 300 observations was constructed by drawing trade prices for the European and American options from an empirical distribution of where the trade price falls within a prevailing bid-ask spread. Then, the simulated American trade price is regressed on the simulated European trade price and the coefficients and standard errors are stored. This process is repeated 1,000 times. The empirical distributions used are Vijh (1990), Hemler and Miller (1996), and Miller (1992). Because the distributions reported by Vijh and Hemler and Miller are so similar, only results from the Vijh distribution are compared to results generated by the more disperse distribution in Miller (1992).

Panel A. Empirical distributions of where trade prices fall within a prevailing bid-ask spread.

	Vijh (1990)[1]	Hemler and Miller (1996)[2]	Miller (1992) SPX Calls	Miller (1992) SPX Puts
The Percentage of Trades Where the Trade Price is:				
Higher than the ask price	2.5	0.1	15.7	17.8
Equal to the ask price	40.9	40.2	22.8	25.5
Between the ask price and the spread midpoint	4.5	7.6	11.4	11.2
Equal to the spread midpoint	17.1	14.7	3.8	4.3
Between the spread midpoint and the bid price	3.8	6.1	11.7	10.7
Equal to the bid price	29.2	31.4	22.3	20.6
Lower than the bid price	1.9	0.0	12.4	9.9

[1]CBOE equity call and put options during March and April of 1985.
[2]S&P 500 Index Options (SPX) in September and early October 1987.
[3]S&P 500 Index Options (SPX) during January, February, and March 1989.

Level Regression: $American = \alpha + \beta(European) + \epsilon$	$\hat{\alpha}$	$\hat{\beta}$	Log Regression: $LN(American) = \alpha + \beta[LN(European)] + \eta$	$\hat{\alpha}$	$\hat{\beta}$
Panel B. Mean Regression Coefficients From a Simulation Using the Vijh (1990) Distribution With a Larger Bid-Ask Spread Assumed for the American Option					
Simulation Mean	0.021	1.026	Simulation Mean	0.029	0.999
True Value	0.000	1.030	True Value	0.030	1.000
95% Confidence Interval:			95% Confidence Interval:		
Low	-0.234	0.999	Low	0.015	0.993
High	0.270	1.053	High	0.042	1.005
Panel C. Mean Regression Coefficients From a Simulation Using the Miller (1992) Distribution					
Assuming a Larger Bid-Ask Spread for the American Option					
Simulation Mean	0.452	1.026	Simulation Mean	0.034	0.997
True Value	0.000	1.030	True Value	0.030	1.000
95% Confidence Interval:			95% Confidence Interval:		
Low	-0.385	0.979	Low	0.013	0.988
High	0.456	1.072	High	0.055	1.001
Assuming a Larger Bid-Ask Spread for the European Option					
Simulation Mean	0.044	1.026	Simulation Mean	0.035	0.997
True Value	0.000	1.030	True Value	0.030	1.000
95% Confidence Interval:			95% Confidence Interval:		
Low	-0.369	0.985	Low	0.016	0.989
High	0.440	1.066	High	0.054	1.006
Assuming Equal Bid-Ask Spreads for the American and European Options					
Simulation Mean	0.071	1.025	Simulation Mean	0.038	0.997
True Value	0.000	1.000	True Value	0.030	1.000
95% Confidence Interval:			95% Confidence Interval:		
Low	-0.345	0.984	Low	0.017	0.987
High	0.484	1.069	High	0.057	1.006

Panel D. 95% Confidence Intervals on the Mean Early Exercise Premium

Vijh (1990) Distribution and Larger Bid-Ask Spread for the American Option

True Value		From Data	From Level Regression	From Log Regression
0.03	Mean	.0282	.0293	.0271
	95% Low	.0226	.0050	.0216
	95% High	.0336	.0540	.0326

Miller (1992) Distribution and Larger Bid-Ask Spread for the American Option

True Value		From Data	From Level Regression	From Log Regression
0.03	Mean	.0313	.0332	.0289
	95% Low	.0236	-0.009	.0213
	95% High	.0391	.0689	.0367

Miller (1992) Distribution and Equal Bid-Ask Spreads

True Value		From Data	From Level Regression	From Log Regression
0.03	Mean	.0319	.0342	.0299
	95% Low	.0248	-0.0005	.0227
	95% High	.0388	.0672	.0367

Miller (1992) Distribution and Larger Bid-Ask Spread for the European Option

True Value		From Data	From Level Regression	From Log Regression
0.03	Mean	.0335	.0370	.0311
	95% Low	.0254	.0024	.0231
	95% High	.0416	.0743	.0393

TABLE 5

Mean Profitability of Apparent Arbitrage Opportunities when the Trade Occurs Either at the Midpoint of the Bid-Ask Spread or at the Relevant Bid and Ask Prices. Using the original 993 combined raw matched pairs to identify the time of the American quote, we scan the CBOE tape for two matching European quotes: the closest one before and the closest one after the American quote. In some cases, there is no European quote before the American quote. These observations are discarded as well as observations with quotes equal zero, days to expiration less than 5, and an absolute value between the midpoint of the quotes greater than $3.00. This results in a sample of 467 call observations and 346 put observations. When observations before 9:30am are excluded, the sample size is 217 calls and 134 puts. For these two subsets, we conduct the following simulations. At the time of each observed American quote, we 1) compare the observed American midpoint to the prevailing European midpoint and 2) compare the observed American ask to the prevailing European bid. In addition, we calculate theoretical European option quote using data from the prevailing quotes to calculate an implied standard deviation and the cash index level at the time of the American quote. Then, we 3) compare the observed American midpoint to the theoretical European midpoint and 4) compare the observed American ask to the theoretical European bid. In each comparison, if the American price is less than the European price, we call this an 'apparent arbitrage.' We assume a transaction fee of $5 per contract and assume traders will conduct an arbitrage strategy only if the price differential exceeds this fee. We then "leg-on" an arbitrage in two ways. In the first way, we assume that the trader receives price improvement on both sides of the trade. That is, the trader buys the American option at the midpoint of the current, observed bid-ask spread and sells the European option at the midpoint of the next *observed* European quote. In the second way, we assume the trader receives no price improvement. That is, the trader buys the American option at the ask price of the current, observed quote and sells the European option at the bid price of the next *observed* European quote. (Mean losses are in parentheses).

Apparent Arbitrages			Execution at Spread Midpoints			Execution at Relevant Bid/Ask		
		Mean	Mean	Winners		Mean	Winners	
Signal Used by Trader	N	Profit	Profit	N	Profit	Profit	N	Profit
Panel A. All Call Observations								
1) Observed American Midpoint less than Prevailing European Midpoint	170	$27	$27	113	$51	($32)	36	$48
2) Observed American Ask less than Prevailing European Bid	18	62	133	18	133	73	15	96
3) Observed American Midpoint less than Theoretical European Midpoint	185	37	22	117	49	(32)	35	50
4) Observed American Ask less than Theoretical European Bid	33	48	84	27	107	21	19	78

Apparent Arbitrages			Execution at Spread Midpoints			Execution at Relevant Bid/Ask		
		Mean	Mean	Winners		Mean	Winners	
Signal Used by Trader	N	Profit	Profit	N	Profit	Profit	N	Profit
Panel B. All Put Observations								
1) Observed American Midpoint less than Prevailing European Midpoint	94	$23	$15	56	$38	($38)	12	$53
2) Observed American Ask less than Prevailing European Bid	11	48	105	11	105	52	8	78
3) Observed American Midpoint less than Theoretical European Midpoint	143	28	11	84	33	(42)	15	46
4) Observed American Ask less than Theoretical European Bid	26	38	52	21	66	(5)	9	68
Panel C. Call Observations After 9:30am Only								
1) Observed American Midpoint less than Prevailing European Midpoint	82	$28	$23	51	$50	($33)	20	$34
2) Observed American Ask less than Prevailing European Bid	7	61	117	7	117	55	6	73
3) Observed American Midpoint less than Theoretical European Midpoint	92	34	18	56	48	(38)	20	34
4) Observed American Ask less than Theoretical European Bid	15	46	95	14	104	31	12	50
Panel D. Put Observations After 9:30am Only								
1) Observed American Midpoint less than Prevailing European Midpoint	30	$31	$15	19	$39	($37)	4	$34
2) Observed American Ask less than Prevailing European Bid	3	36	88	3	88	36	2	65
3) Observed American Midpoint less than Theoretical European Midpoint	40	31	19	29	35	(33)	6	32
4) Observed American Ask less than Theoretical European Bid	8	38	49	6	67	(16)	2	59