An empirical study on the early exercise premium of American options: Evidence from OEX and XEO options*

Weihan Li†
Department of Accountancy and Finance
Otago Business School, University of Otago
Dunedin 9054, New Zealand
weihan.li@postgrad.otago.ac.nz

Jin E. Zhang
Department of Accountancy and Finance
Otago Business School, University of Otago
Dunedin 9054, New Zealand
jin.zhang@otago.ac.nz

Xinfeng Ruan
Department of Finance
International Business School Suzhou, Xi'an-Jiaotong Liverpool University
Suzhou 215000, China
Edwin.Ruan@xjtlu.edu.cn

Pakorn Aschakulporn
Department of Accountancy and Finance
Otago Business School, University of Otago
Dunedin 9054, New Zealand
pakorn.aschakulporn@otago.ac.nz

First Version: 30 September 2022
This Version: 9 June 2023

Keywords: American-style, European-style, OEX, Early Exercise Premium, Liquidity
JEL Classification Code: G12,G13,G14

---

* ACKNOWLEDGEMENTS
† Corresponding author.

An empirical study on the early exercise premium of American options: Evidence from OEX and XEO options

Abstract

Since the S&P 100 Index underlies both American (OEX) and European (XEO) options, the value of the early-exercise premium of American options can be directly observed. We find that the mid-quote of a XEO option can be higher than that of an otherwise identical OEX option, and liquidity can explain this overpricing phenomenon of European options. Our results show that illiquid options are significantly overpriced in the S&P 100 Index options market. This finding indicates that an illiquid option can be overvalued with a higher market offer price, which is the requirement of market makers for compensation to provide the liquidity.

Keywords: American-style, European-style, OEX, Early Exercise Premium, Liquidity
JEL Classification Code: G12,G13,G14

1 Introduction

This paper investigates the early exercise premium (EEP) of American options employing the data from the S&P 100 Index options market. The S&P 100 Index underlies both American (OEX) and European (XEO) options, making it a clean and fertile land to analyze the premium difference between options with two different exercise styles. The valuation differences of American-style and European-style derivatives have been widely researched, while these studies either cannot directly collect the EEP from the market, they instead derive the EEP from models (e.g., Figlewski, 2022) or compare different derivatives with different exercise styles (e.g., Li and Zhang, 2011; Jin, Zhao, and Luo, 2022). We find that the EEP of an American option is not always positive. Since the trading volume of OEX options is significantly larger than that of XEO options and liquid assets can be more accurately priced (Amihud and Mendelson, 1986), we regard the premium of OEX options as the benchmark. The directly observed negative EEP (NEEP) indicate that European options can be overpriced in the S&P 100 Index options market, reflecting plentiful arbitrage opportunities for investors to earn substantial profits. Although these arbitrage opportunities drop dramatically after considering market frictions like the bid-ask spreads, the overvalued phenomenon of XEO options is still significant, which is contrary to the classic option-pricing theory. Our results show that the NEEP of American options in the S&P 100 Index options market can be explained by liquidity. The illiquid XEO options are charged at higher prices, especially the ask price, by the market maker, which can be regarded as the compensation for providing the liquidity in the options market (Deuskar, Gupta, and Subrahmanyam, 2011).

During the last three decades of the 20th century, the valuation of American options was a popular subject among academics, who forwarded different approaches to estimate the EEP for pricing American options more accurately.[1] These methods have been

[1] We have listed details of these papers in Appendix A.

employed in numerous empirical studies. Despite most numerical solutions for pricing American options being derived from the valuation formula of European options, only a few empirical studies have compared American to their corresponding European options. Therefore, this paper makes original contributions to this field by investigating the EEP using the directly observed market data of American options and European counterparts.

OEX options used to be the most popular index options market before the emerging Exchange-Traded Funds (ETFs) and other index options, and then the Chicago Board of Options Exchange (CBOE) launched XEO options to attract more investors on July 23, 2001. Although the trading volume of XEO options is not as high as that of OEX options, it still makes the S&P 100 Index options market more competitive due to the feature that it trades both European and American options simultaneously. However, with the development of the global derivative market, there has been an notable increase in both ETFs and index options. These emerging options traded on ETFs (e.g., SPY, DIA, and RUSS) are American-style, while index options (e.g., VIX, Russell 2000, and NASDAQ) are all European-style, suggesting that the directly observed EEP data cannot be available. Consequently, the S&P 100 Index options market is still unique among these emerging derivatives. Besides, the explanation from the CBOE for why keeping OEX is that it is grandfathered in derivatives even though its popularity has reduced drastically. Overall, it is meaningful to explore the EEP in the S&P 100 Index options market, since it is original derivative market with the available market data of the different exercise-style options. Then, the outcomes can also be applied to other options markets as the benchmark.

According to option-pricing theory, the EEP can be valueless in some cases. More specifically, an American call option is supposed not to be exercised before maturity or dividend payments, since it can waive the remaining time value of the call, which is always positive (Merton, 1973; Hull, 2003; Chance and Brooks, 2015). Combining it with the no-arbitrage principle, an American option must always be at least as valuable as an otherwise identical European option due to the right of early-exercise. The value added is known as the EEP (McDonald, 2013). Given these two laws, the value of an American call should be the same as the value of an otherwise identical European call if the underlying pays no dividends. Under this circumstance, an American call is supposed not to be early exercised until expiration, which makes the exercise style similar to a European one, and, theoretically, the right of early exercise will be valueless.

However, we find that the theoretically consistent prices of American and European calls does not hold in practice. Our results indicate that only 5.571% matched OEX and XEO calls, which are both written on the S&P 100 Index, have the same market value during the first decade since the launch of XEO options, and approximately 86.422% American calls reflect the EEP. Meanwhile, we also document that 8.007% XEO calls are more valuable, implying the NEEP of American calls which entirely breaches option-pricing theory. This finding is of interest since it implies that there exists an instant arbitrage opportunity for market participants. Since the theoretical values of OEX and XEO call options are supposed to be the same, investors can profit by longing the relatively cheaper American calls and shorting the same contracts of relatively expensive European ones, and then hold to maturity. Unlike calls, the classic option-pricing theory argues that American put options are supposed to be more valuable than the otherwise identical European put options regardless of dividends. Therefore, investors can only profit once the market price of an American put is lower than that of its European counterpart which indicates the NEEP, and around 7.705% matched puts in our sample suggest the instant arbitrage opportunities. The frequent overpricing phenomenon of the European options evidently violates conventional theory in the S&P 100 Index options market.

Indeed, the EEP of American options has been widely documented by existing literature in several dimensions. Battalio, Figlewski, and Neal (2020) report that the best market bid of an ITM American equity option can be below its intrinsic value, which is the payoff of early-exercise, even observed at one-minute interval throughout the day. In this condition, an American call should be liquidated by early-exercise to recover its intrinsic value instead of selling at the best market bid if the investor has to liquidate the position. Then, Figlewski (2022) derives the liquidity value of the right of early-exercise in a closed form based on a function of the bid-ask spread, and empirically shows that such liquidity value can be larger than the theoretical value of early-exercise for earning a dividend. These two papers illustrate the EEP when option holders have to liquidate their position, while Jensen and Pedersen (2016) compare early-exercise and delta-hedging until the maturity, who argue that it is optimal to early exercise the option when the early-exercise can contribute to the reduction of costs in short-sale, transaction, or funding. By considering financial frictions, Jensen and Pedersen (2016) theoretically and empirically provide rational reasons of early-exercises to previous studies, which primarily focus on irrational reasons, e.g., irrational early-exercise decisions (Finucane, 1997; Poteshman and Serbin, 2003), irrational failures of exercise of call options (Pool, Stoll, and Whaley, 2008) and put options (Barraclough and Whaley, 2012). The other components of the EEP reported by researchers are the bias of the Black-Scholes model in estimating the value of American options and the wildcard premium embedded in cash-settled American options.[2]

The aforementioned EEP increases the value of American options, however, only a few studies document the NEEP, which implies that the corresponding European options have a higher market price. Lee and Nayar (2000) report that 47% of calls and 58% of puts in their sample reflect the NEEP, which are higher than the findings of McMurray and Yadav (2000) (32% of calls and 17% of puts, respectively). Moreover, Lee and Nayar

[2] See Fleming and Whaley (1994); Dueker and Miller Jr (2003); Lasser and Spizman (2016).

(2000) also find the presence of arbitrage opportunities in approximately 22% and 24% of these overpriced calls and puts, respectively, even after considering actual retail transaction costs. Nevertheless, Lee and Nayar (2000) fail to account for the bid-ask spreads which traders have to trade within to benefit from these arbitrage opportunities. In addition, Dueker and Miller Jr (2003) find a lower frequency of this overpricing phenomenon, 17.6% for calls and 8.7% for puts, and only 1.5% is left for calls and less than 1.0% for puts after conducting arbitrage tests with considering bid-ask spreads. Although these paper report the NEEP, none of them have explained the reason, and this paper aims to full this gap. We mainly consider the EEP resuts from the Black-Scholes world, i.e., we control the EEP of exercise-based differences (EBD) to make the overvalued phenomenon of European options more obvious, and compare the remaining value of OEX and equivalent XEO options. Although we subtract EBD from the original EEP, there could exist transaction cost savings (TCS), wildcard premium (WC) and other sources of EEP we did not capture in the market. Therefore, American options are still expected to be at least as valuable as otherwise identical European options. However, we find that 14.974% of matched calls and 13.268% of matched puts in our sample indicate the substantial NEEP, and the average is 0.035 and 0.013, respectively, revealing that the overestimation of the value of European options is common in the S&P 100 Index options market.

Given the frequent overvaluation phenomenon and the large gap between the trading volume of OEX and XEO options, it is reasonable to infer that there are potential liquidity issues contributing to the NEEP. Our results indicate that illiquidity can pose a statistically and economically significant impact on the observed market NEEP. Options with wider spreads and lower trading volume can be overpriced, which is in line with Deuskar, Gupta, and Subrahmanyam (2011) who find that market makers may charge for a compensation for providing liquidity in the options market, leading to the higher market offer prices.

Our contributions are numerous. First, to the best of our knowledge, this paper is the first to investigate the reasons of the NEEP of American options and makes original contributions to the existing literature. Cao and Yadav (2021) provide significant sources of the EEP using different pricing models, however, they fail to document the NEEP. Although Dueker and Miller Jr (2003) report the NEEP of American options, they cannot explain how this phenomenon comes into being. We provide abundant evidence of the existence of the NEEP and also empirically show how liquidity can impact the NEEP. Second, this paper supports previous literature against the never-early-exercise principle with significant results. For American option holders looking to liquidate their positions, early exercising can be optimal once the payoff of early-exercise is larger than the best market bid (Battalio, Figlewski, and Neal, 2020; Figlewski, 2022). Besides, the existence of the NEEP itself is a breach of the traditional option-pricing theory. Third, our findings contribute to previous studies on comparison of prices of derivatives. For instance, Li and Zhang (2011) emphasize the price difference between European style warrants and options, and Jin, Zhao, and Luo (2022) focus on European style warrants and American style options. We extend these papers by investigating the same derivatives with different exercise styles based on the unique feature of S&P 100 Index options market. Furthermore, our empirical results also provide evidence to literature focusing on the effect of liquidity on asset pricing, and extend the argument of Deuskar, Gupta, and Subrahmanyam (2011) from over the counter (OTC) currency rate options to equity index options, and strongly support that the effect of liquidity on asset prices should not be generalized without accounting for market features.

The remainder of this paper is organized as follows. In Section 2, we discuss the theoretical frameworks. Then, in Section 3 we display our data, liquidity measures and other variables, and also present the results to empirically show evidence of the influence of different factors on the NEEP in Section 4. Finally, we conclude this paper in Section 5.

2 Theoretical Framework and Hypotheses Development

In this section, we present relevant option-pricing theory, and, then, explain how the right of early exercise as well as liquidity can contribute to the option premium.

2.1 Classic Option Pricing Theory

The difference between an American option and an otherwise identical European option is the exercise style, i.e., the right of early exercise. Since the American option can be exercised at any time before and at maturity, its value is supposed to be no lower than an equivalent European option. Besides, if the right of early-exercise becomes worthless, then an American call option should be never exercised early before maturity or dividend payments, and can be regarded as a European option. The value of a call option is composed of two parts, the intrinsic value, and the time value. The time value of the call option also contains two dimensions, the value of optionality and interests earned by delaying the payment of the strike price. Then, the value of an American call written on a non-dividend paying stock can be easily obtained by the put-call parity, which can be written as

$$C_E(S_t, K, T-t) = (S_t - K) + P_E(S_t, K, T-t) + K[1 - e^{-r(T-t)}] \tag{1}$$

where C_E and P_E denote the value of a European call and put, respectively, S_t is the stock price at time t, K is the strike price, T is the maturity date, and r is the risk-free rate. The three terms on the right side of the equal sign are the payoff of the immediate exercise, the value of optionality, and interests earned by delaying of the payment of the strike price, respectively. It is obvious that the call option is more valuable when the first term is positive, which is the intrinsic value and only exists in the in-the-money options. Besides, the value of optionality can also be considered as an implicit put protection should the underlying price become smaller than the strike price. The value of optionality depends on the volatility of the underlying, and, thus, the longer the time to maturity, the more chances the out-of-the-money options can become in-the-money options, which can significantly enhance the value of the call due to the emergence of the intrinsic value. While for the in-the-money options, the value of optionality can be weakened since the possibility of losing their intrinsic value also increases. As for the last term, it can be easily seen that the interests would be larger if the time to maturity becomes longer. Hence, the early-exercise of an American call is theoretically valueless since it can waive its remaining time value which is always positive as long as the risk-free rate is not negative, indicating that there is no EEP.

The early-exercise of an American call can be optimal when the underlying stock pays dividends. There might be a potential loss by deferring receipt of the stock if it pays dividends, which is the third term of the following equation

$$C_E(S_t, K, T-t) = P_E(S_t, K, T-t) + S_t - PV_{t,T}(Div) - PV_{t,T}(K). \tag{2}$$

Once the dividend payment exceeds the remaining time value of the American call, it can be optimal for the option holder to exercise early to receive the dividends. Hence, there should be an EEP for these American calls.

By contrast, it can be rational to early-exercise an American put option whether or not the underlying stock pays dividends. Similarly, the value of an American put written on a non-dividend paying stock displayed via put-call parity is

$$P_E(S_t, K, T-t) = (K - S_t) + C_E(S_t, K, T-t) - K[1 - e^{-r(T-t)}] \tag{3}$$

where the three terms on the right side of the equal sign are the payoff of the immediate exercise, the value of optionality, and interests lost by delaying of the receipt of the strike price. Apparently, there exist opportunities for investors to early exercise once the interests earned by receiving the strike price far surpass the implicit call protection. Unlike American calls, the dividend payments have few influences on the early-exercise of American puts. However, there is no need for an investor to early exercise the American put if the interest rate becomes zero, since he cannot receive any interests from the strike price. Therefore, the EEP of American puts is supposed to be always positive as long as the interest rate is positive.

While the S&P 100 Index itself is just a price return index, which only concentrate on capital appreciation, since investors are not able to invest in it, the index does not include the dividends paid to shareholders in its returns. To invest in the index itself, investors must invest in the fund that tracks it, which is known as OEF and pays the dividends. The S&P 100 Index options are cash-settled without a delivery-mechanism, and OEX option holders are only able to get the payoff of the difference between the strike price and the index level, not the underlying. Therefore, for the price return index, option holders, although the index pay dividends, cannot receive or even reinvest the dividends. Given this circumstance, dividends have no influence on the decision of the early-exercise of OEX calls, leading to the early-exercise for dividends being worthless, and OEX puts are naturally considered more valuable.

2.2 Sources of the EEP

One source that can contribute to the EEP is the EBD, which is the difference between the valuation of American and European options computed in the Black-Scholes world. Lasser and Spizman (2016) control the option characteristics such as implied volatility, maturity, and moneyness, then employ the binomial tree method to obtain the option prices with American and European styles to control the exercise style. The substantial differences between the computed prices come from each node of the model, which are calculated from the Black-Scholes world.

Additionally, although aforementioned classic laws of financial economics regarding option-pricing suggest that American calls should be the same valuable as the otherwise identical European options, they mostly assume that the market is frictionless. On the contrary, illiquidity issues might occur even in highly competitive financial markets, especially during periods of financial turmoil, which might arouse concerns of market participants. Besides, the law of one price can no longer be feasible when such an issue leads to a wedge between the market bid and offer prices (Leippold and Schärer, 2017). Both Battalio, Figlewski, and Neal (2020) and Figlewski (2022) argue that when American option holders have to liquidate their position, it can be optimal to exercise instead of selling at the relatively lower bid price in the market, which is the so-called TCS and certainly makes the right of early-exercise more valuable.

Moreover, a unique characteristic of cash-settled index options is that investors can liquidate their positions without offsetting the corresponding position of the underlying asset. Such a feature could result in the WC period at the end of the trading day, where the market provides investors "bonus" time to determine whether to exercise after the settlement price has been set for the underlying index. Apparently, the WC premium comes from the time difference between the closing time of the underlying security market and the option market, and the bonus 15-minute trading interval can contribute the statistical and economical EEP to OEX options (Fleming and Whaley, 1994; Lasser and Spizman, 2016).

Overall, the sources contributing to the EEP previously mentioned as well as others we neglected can make OEX options more expensive than their XEO counterparts in the S&P 100 Index options market, even though classic option-pricing principles indicate that American calls are supposed to be the same valuable as their equivalent European calls. This leads us to our first hypothesis:

Hypothesis 1 (H1): *OEX options are more valuable than the otherwise identical XEO options.*

2.3 Liquidity

The effect of liquidity on asset pricing has also received considerable attention in previous literature. Unlike other assets like stocks and bonds, the liquidity of options should not simply be assumed as an exogenous phenomenon. More specifically, as options cannot guarantee a perfect hedge, it may result that dealers have to hold as little inventory as possible after hedging, making liquidity reflect the ease of offsetting the trade, which further affects the price of options. Therefore, the level of liquidity in options markets are also a result of risk exposure, as well as the risk appetite and capital constraints of market participants (Deuskar, Gupta, and Subrahmanyam, 2011). In addition, since options traders can also have alternative methods to hedge the potential unhedgeable risk, the buyers and sellers can have different requirements towards illiquidity. The buyers may ask for a lower price to long an illiquid option, while the sellers demand a higher price as the compensation of providing liquidity in the option market, leading to the option price being determined by the specific option market. Therefore, it is not reasonable to argue that liquidity can have similar influence on the underlying price without referring to market features.

The seminal work of the impact of liquidity on asset pricing by Amihud and Mendelson

(1986) provides a theoretical argument that illiquidity caused by a wide bid-ask spread leads to price discounts and higher expected returns. Employing option illiquidity measures constructed from intraday effective bid-ask spreads for a large panel of U.S. equities, Christoffersen et al. (2018) find the risk-adjusted return of illiquid equity options will exceed that of liquid ones, which is 3.4% per day for at-the-money (ATM) calls and 2.5% for ATM puts. While for index options, Li and Zhang (2011) investigate the effect of liquidity on why derivative warrants with European-style are more expensive than options with European-style, which are both written on Hang Seng Index (HSI). Regarding the bid-ask spread as the standard measure of liquidity, Li and Zhang find that derivative warrants are much more liquid than options, and, thus, the overpricing phenomenon can be significantly interpreted by the liquidity difference between derivative warrants and options. In addition, Dueker and Miller Jr (1996) show that after an adjustment to liquidity biases, the EEP of the S&P 500 Index options can increase from $0.06 to $0.26 for calls and from $0.19 to $0.22 for puts. In contrast, Deuskar, Gupta, and Subrahmanyam (2011) find that illiquid options trade at higher prices relative to liquid options. Besides, Deuskar, Gupta, and Subrahmanyam (2011) show that the impact of liquidity on asset prices should not be generalized without considering the corresponding market characteristics. Since the inconclusive implications of these empirical results, we posit that liquidity has an association with the value of options. This leads to our second hypothesis:

Hypothesis 2a (H2a): *Liquidity is positively associated with the EEP of American options in the S&P 100 Index options market.*

Hypothesis 2b (H2b): *Liquidity is negatively associated with the EEP of American options in the S&P 100 Index options market.*

3 Data and Variables

3.1 Data

Daily transaction data for American and European options on the S&P 100 Index traded on the CBOE are provided by OptionMetrics. The data set spans over a twenty-year period from the inception of XEO options on 23 July 2001 to 31 December 2021. The dividend yields are also provided by OptionMetrics and daily interest rates are computed by linearly interpolating and extrapolating the US Treasury yield rate, which is collected from the U.S. Department of the Treasury website. [3] Several filters for the option sample are applied. According to Figlewski (2022), several previous studies eliminate the days when the market bid is so low that it is more optimal for holders to early exercise the options instead of selling in the market when they need to liquidate their positions. Thus, we first require that the best market bid is supposed to be higher than zero as well as no more than the best market offer. Moreover, the premium of each option must be no less than 0.125, and options with missing implied volatitlities are discarded. Additionally, we discard observations with zero open interest to ensure the potentiaial liquidation or early exercise. Then, we match options with different exercise styles but same strike and maturity together, and regard the midquote of each option as the fundamental value. Therefore, the EEP can be directly observed from the market midquote difference between the OEX option and its XEO counterpart. Besides, this paper generally considers options with moneyness from -0.20 to +0.20, as well as maturities between 7 and 360 days. After we apply these filters, our sample consists of 184,050 matched calls and 226,558 matched puts from the original data.

We divide the entire matched sample into 25 groups according to moneyness and maturity. Moneyness is defined as $M = 1 - K/S$ for calls and $M = K/S - 1$ for

[3] The U.S. Department of the Treasury website is https://home.treasury.gov/.

puts (K is the option strike price and S is the settlement price of the underlying). The options are divided into 5 groups, $-0.20 < M \leq -0.10$ (deep-out-of-the-money (DOTM)), $-0.10 < M \leq -0.02$ (out-of-the-money (OTM)), $-0.02 < M \leq +0.02$ (at-the-money (ATM)), $0.02 < M \leq +0.10$ (in-the-money (ITM)), and $0.10 < M \leq +0.20$ (deep-in-the-money (DITM)). Maturity is measured by the number of days to expiration, and it is also divided into 5 groups, $7 < TTM \leq 30$, $30 < TTM \leq 60$, $60 < TTM \leq 120$, $120 < TTM \leq 180$, and $180 < TTM \leq 360$. As shown in Figure 1, it is clear that the S&P 100 Index displays an upward tendency with fluctuations, ranging from the minimum with 322.13 on 9 March, 2009 to 2,194.58 at the end of 2021, almost seven times the index during the GFC. This indicates that although both being categorized into the same group, the premiums can vary a lot. For instance, the market price of an ATM OEX put expiring within one month is 10.7 on 9 March 2009, while 38.1 on 3 December 2021. Thus, the premium differences of each group across various durations should not be directly summerized together. According to Li and Zhang (2011), the option price data can be comparable across time via normalizing by the underlying index. Following this method, the premiums of OEX and XEO options are standardized by the underlying and expressed in terms of the percentage of the S&P 100 Index level.

[Insert Figure 1 about here.]

Li and Zhang (2011) and Jin, Zhao, and Luo (2022) argue that the liquidity difference can have strong explanatory power for overpricing behavior, especially for low moneyness derivatives. Both investigate the price differences between warrants and options, and find a large gap in liquidity between the two markets that lower liquidity results in the weaker efficiency on asset pricing. However, Deuskar, Gupta, and Subrahmanyam (2011) find that in OTC derivative markets, illiquid options are more expensive than liquid options. Overall, existing literature has empirically proved that the influence of liquidity can pose a significant impact on the option premium. As for S&P 100 options market, Figure 2 shows that the trading volumes of the both options have a downward trend after

2010. During the last six years in the sample, the mean daily trading volume of OEX option is 2,664, while the mean daily trading volume of XEO option is 364. Since the launch of XEO options, there has been an notable increase in options both on indexes, which is cash settled, and on exchange traded funds (ETFs). However, all cash-settled options appeared during the period are European-style, like the VIX, VXX, Dow Jones, NASDAQ 100, and so on. By contrast, options traded on ETFs are American-style with an underlying asset delivery mechanism, like the SPY. Meanwhile, the trading volume of OEX options has dropped dramatically and is virtually nonexistent currently. As for XEO options, the trading volume has been exceptionally low since its inception. Lasser and Spizman (2016) also document this phenomenon. Lasser and Spizman consulted the CBOE about the reason why there are still American options trading on the S&P 100 Index, and the explanation from the CBOE is that although the popularity of OEX has been reduced, it has been grandfathered. Therefore, in order to make the investigation of premium differences between OEX and XEO options more precise and avoid potential biases from market illiquidity, we discard the period when the trading volume shows an extraordinary decrease and further analyze the results during the relatively more liquid market period from 23 July 2001 to 31 December 2010,[4] which is the primary sample period of this study, indicating that the comparison is always under the situation that OEX and XEO options are both relatively liquid.

[Insert Figure 2 about here.]

3.2 Variables

The main dependent variable is the EEP which can be directly observed by the market premium difference of each matched pair. In this paper, we employ the standardized EEP as the proxy, which can clearly reflect the scale of the premium, and is defined as the premium difference standardized by the underlying level, EEP. Thus, EEP of the ith

[4] We also estimate the results of the whole sample period, which are almost the same.

pair at time t can be written as

$$EEP_{i,t} = \frac{AmericanMidquote_{i,t} - EuropeanMidquote_{i,t}}{S\&P100Index_t}. \tag{4}$$

Intuitively, if the outcome is negative, it should be the NEEP, which is denoted by $NEEP$.

According to Amihud (2002), liquidity plays an important role in asset pricing, which has many different facets. After finding the NEEP, i.e., the overpricing phenomenon of illiquid European options, in the S&P 100 Index options market, we interpret this using the influence of liquidity, which is measured by the bid-ask spread and trading volume in dollars of each option following Li and Zhang (2011), and Leippold and Schärer (2017). Therefore, the spread between bid and ask prices, and trading volume is considered as our core explanatory variables. We define the spread difference, *Spread*, as the negative of difference between the ratio of the bid-ask spread and the mid-quote of an American option and the otherwise identical European option. Thus, the higher the *Spread*, the more liquid the American option. We also express *Spread* as a proportion of the underlying index level, which is given by

$$Spread_{i,t} = -(AmericanSpreadRatio_{i,t} - EuropeanSpreadRatio_{i,t}), \tag{5}$$

where

$$AmericanSpreadRatio_{i,t} = \frac{AmericanSpread_{i,t}}{AmericanMidquote_{i,t}}, \tag{6}$$

$$EuropeanSpreadRatio_{i,t} = \frac{EuropeanSpread_{i,t}}{EuropeanMidquote_{i,t}}. \tag{7}$$

Then, we define the difference of trading volume in dollars, DV, for the ith option pair at time t as

$$DV_{i,t} = \frac{AmericanDV_{i,t} - EuropeanDV_{i,t}}{S\&P\ 100Index_t}, \tag{8}$$

where

$$AmericanDV_{i,t} = \frac{AmericanMidquote_{i,t} * AmericanTradingVolume_{i,t}}{1000}, \tag{9}$$

$$EuropeanDV_{i,t} = \frac{EuropeanMidquote_{i,t} * EuropeanTradingVolume_{i,t}}{1000}. \tag{10}$$

We principally investigate factors that may affect the NEEP. The control variables considered include risk-free rate (Rf), dividend yield (DY), and implied volatility of the underlying index (Vol). Moreover, since we primarily account for the EEP from the Black-Scholes world, it is essential to reduce the influences of it when comparing the premium differences of the two options. Following the approaches employed in Lasser and Spizman (2016), who also use the daily data, we are able to obtain the EEP of EBD. More specifically, Lasser and Spizman (2016) employ a 400 period Cox, Ross, and Rubinstein (1979) type binomial tree model with continuous dividends to obtain the value of the OEX (AME_{OEX}) and XEO (EUR_{XEO}) options with their own corresponding implied volatilities. We also get the theoretical value of an American option using the XEO implied volatility (AME_{XEO}). Then, the difference between AME_{XEO} and EUR_{XEO} is only resulted from the Black-Scholes world, and, thus, it is regarded as the EEP from the EBD.[5] Hence, the EEP from EBD can be computed via

$$EBD_{i,t} = \frac{AME_{XEO_{i,t}} - EUR_{XEO_{i,t}}}{S\&P100Index_t}. \tag{11}$$

Based on Battalio, Figlewski, and Neal (2020), and Figlewski (2022), whether the lower bid issue occurs in OEX market need to be investigated. Then, we define the EEP

[5] Lasser and Spizman (2016) define this premium as $AME_{OEX} - EUR_{XEO}$, which is not in line with their argument theoretically as well as empirically. Besides, they argue that WC is the gap between AME_{OEX} and AME_{XEO}. However, this difference contains all sources of the EEP due to the different implied volatilities in the options market, like WC, potential volatility and jump risks.

from TCS when liquidating an ITM option position as

$$TCS_{i,t} = \max\left[\frac{IntrinsicValue_{i,t} - Bid_{i,t}}{S\&P\ 100Index_t}, 0\right]. \tag{12}$$

Since the EBD has been determined, we subtract it to make whether XEO options are overvalued more clear. Other than the TCS and the WC premium, there may exist other sources in the S&P 100 Index options market contributing to the EEP. Therefore, OEX options are still expected to be at least as valuable as XEO options. Then, the remaining value of the premium gap, $Remain$, is defined as

$$Remain_{i,t} = EEP_{i,t} - EBD_{i,t}. \tag{13}$$

Similarly, if the outcome is negative, it should be the negative remaining EEP, which is denoted as $NRemain$.

In Table I, we list the descriptive statistics for the variables constructed. To avoid the aggregate liquidity factor being driven by extreme values, we winsorize all variables at the 1% and 99%. Table I shows that the average EEP is positive. Although the average of $Remain$ is also positive, it is clear that $Remain$ is generally smaller than EEP due to the deduction of EBD of the EEP. It can also be seen that the standard deviation of $Remain$ decreases after accounting for EBD, indicating that the value of the EEP is not always positive for each American option. Furthermore, the difference between $NEEP$ and $NRemain$ is only 0.003% of the underlying level, indicating the EBD of the NEEP American options is relatively small. However, the observations of $NRemain$ are almost double those of $NEEP$. The liquidity measure $Spread$ and DV suggest that OEX options are more liquid than XEO options, which is consistent with Figure 1. The average Rf is around 1.864%, slightly lower than the contemporaneous DY which is approximately

1.830%. The average of Vol is about 0.035, suggesting that S&P 100 Index is relatively volatile during the sample period.

[Insert Table I about here.]

4 Empirical Results

4.1 The NEEP and Instant Arbitrage Opportunities

In this subsection, we first compare the average premium of OEX and XEO options, and then, document the NEEP of American options. First, Panel A of Table II reports the number of observations of matched options. Unlike matched call options, investors tend to hold more OTM put options, especially with expiration within two months. Then, Panel B and Panel C of Table II report the market premium of OEX and XEO options standardized by the corresponding S&P 100 Index level, EEP. We find that the standardized premium of both OEX and XEO put options can be relatively lower than calls in the same group, which is also documented in other papers (e.g., Dueker and Miller Jr, 2003; Li and Zhang, 2011; Lasser and Spizman, 2016). From Panel D of Table II, we can clearly discover that the standardized premium of an American option is significantly larger than that of an otherwise identical option with European-style, which strongly supports **H1**.

[Insert Table II about here.]

Then, we further report to what extent the premium of an American option is larger than that of an otherwise identical European option or whether there are XEO options more expensive than OEX options, scilicet the NEEP that is contrary to the classic option-pricing theory, in Table III. From Table III, it is clear that the market prices of only 5.571% of matched calls are the same, suggesting the theoretical consistent price of American and European calls may not hold in practice. Besides, the NEEP is most frequent in DOTM groups without intrinsic value. This is supported by the findings in

Deuskar, Gupta, and Subrahmanyam (2011), who argue that illiquid options are charged for higher prices compared with liquid options. As shown in Figure 1, although both OEX and XEO markets are relatively liquid before 2011, the OEX market is far more liquid than the XEO market, aggravating the mispricing issue of overestimating the value of XEO options. In addition, the DOTM options are less liquid, which may also exacerbate this overvaluation situation. Thus, the highest percentage of the total NEEP is 14.424% for calls and 14.322% for puts in the DOTM group. Then, this phenomenon almost vanishes with the growth of moneyness, especially for ITM options due to the existence of the intrinsic value.

As for the maturity groups, the percentages also show a decline with the growth of maturity. Theoretically, the value of a call option consists of two components: its intrinsic value as well as time value. The former exists only in ITM options, which makes the premium of ITM option climb more drastically, while the latter is composed of the value of optionality and interests earned by delaying the payment of the strike price. The time value of an option should be always positive as long as the corresponding interest rate is positive, and increase with the growth in maturity. As maturity decays, the potential that an OTM option changes into ITM, which is the value of optionality, is smaller. Thus, the likelihood of early exercise to obtain the intrinsic value created by the optionality becomes smaller as well, leading to the premium of an American option closer or even equal (when the dividend yield is smaller than the contemporary interest rate) to an identical European option. Consequently, the overestimation of the value of XEO calls can be more obvious in the short-term maturity groups, on the ground that the value of the optionality of OEX calls in these groups is lowest. Overall, Table III evidences that **H1** is supposed to be more reasonable.

[Insert Table III about here.]

The classic option-pricing theory indicate that American calls should be the same valuable as the otherwise identical European calls, and American callls should be more expensive. Given that there exist American options are less valuable than European options in the S&P 100 Index options market, it is essential to further investigate the NEEP since the existence of the NEEP strongly evidences **H1** cannot hold in the market, and indicates that there might have some theoretically immediate arbitrage opportunities. Whenever the value of an American option is lower than that of an equivalent European option, which is the NEEP as documented in Lee and Nayar (2000), McMurray and Yadav (2000), and Dueker and Miller Jr (2003), an investor can directly make an arbitrage profit by shorting multiple European options and longing the same contracts of American options, and then hold to maturity. Since the American and European options are written on the same underlying, which means with identical strike and maturity the payoffs are the same at expiration, the investor can directly earn a profit at the premium difference through this buy-and-hold strategy, which is listed in the parentheses of case 3 in Table III.

From Table III, it is clear that the scale of the NEEP is generally slighter than the scale of the EEP. However, it need not imply that the NEEP is not important, since investors can make substantial profits from the arbitrage opportunities. Overall, an investor can profit from this trading strategy at 0.020% of the underlying level from OEX calls and 0.016% of the underlying level from OEX puts. This finding that the instant arbitrage profit of calls is higher than that of puts also support the argument of Deuskar, Gupta, and Subrahmanyam (2011) that since put options are more liquid in the S&P 100 Index options market, market makers may charge less for providing liquidity for puts than for calls, leading to less posibility and scale of NEEP in put options. The higher theoretical value of American puts compared to European counterparts may also be the reason why the average NEEP of OEX put is smaller.

4.2 Market Frictions

Why is the popularity of the S&P 100 Index options market still gradually declining with abundant arbitrage opportunities these days? Nevertheless, as suggested by Dueker and Miller Jr (2003), such an immediate arbitrage opportunity can vanish after considering market frictions like the bid-ask spreads. Then, following Dueker and Miller Jr (2003), we examine whether the immediate arbitrage opportunities still exist after considering the bid-ask spreads. In this case, the instant arbitrage opportunity only emerges when the best available bid price of a European option is higher than the best available ask price of an equivalent American option. Therefore, we discard observations that the market bids of XEO options are smaller than the market offers of OEX options to further analyze the buy-and-hold strategy. Not surprisingly, in our 98,417 matched calls and 124,099 matched puts sample, only 14 pairs of matched calls and 16 pairs of matched puts can produce the arbitrage profits, merely 0.013% of the whole sample have an average profit of 0.25 dollars for call options and 0.22 dollars for put options after applying the filter, which are displayed in Table IV. It is obvious that the impact of bid-ask spreads are significant for this trading strategy, and only few arbitrage opportunities exist. Investors seem not to grasp the chance since the trading volumes of OEX and XEO options are not the same. Another point also worth mentioning is that all of these cases occurs before the GFC, after which no instant arbitrage opportunity appears.

[Insert Table IV about here.]

Since previous studies emphasize the influence of bid-ask spreads on the optimal exercise decision (Dueker and Miller Jr, 2003; Jensen and Pedersen, 2016; Figlewski, 2022), we then regard them as a measure of the market friction. Due to the feature of early exercise, an American option is supposed to be sold or bought at a higher price than an otherwise identical European option in the market. Therefore, we investigate whether there are abnormal market bid or ask prices of OEX options less than these of XEO options. From Table V, our finding shows the market bid prices of XEO options can be higher than the market bid prices of OEX options, which supports Battalio, Figlewski, and Neal (2020) that American options are usually priced at lower market bid prices. Additionally, percentages of the abnormal market offer price in Table V demonstrates that the NEEP of market offer price is more frequent than that of market bid price. According to Deuskar, Gupta, and Subrahmanyam (2011), the reason for this can be that market makers require a high compensation for providing liquidity in the illiquid options market. We also track whether the abnormal bid and ask prices can persist during the life-span of an option, and find that these mispricings appear randomly.

[Insert Table V about here.]

4.3 Illiquidity

Given the NEEP is frequently occuring in market bid and offer prices violating the option-pricing theory, and previous studies highlight the influence of liquidity on asset pricing (e.g., Amihud and Mendelson, 1986; Brenner, Eldor, and Hauser, 2001; Amihud, 2002; Deuskar, Gupta, and Subrahmanyam, 2011; Christoffersen et al., 2018), we compare the liquidity differences between OEX and XEO options by regarding the bid-ask spreads and the trading volume in dollars as the measures of liquidity introduced in Section 3.

In Panel A of Table VI, we outline the proportion of the liquidity of the OEX options not smaller than that of the matched XEO options. In each group, the proportion is greater than 60%, indicating OEX options are generally more liquid than XEO options. In addition, it is clear that the propotion of *Spread* drops with the growth of moneyness, which means that the OTM European options are more illiquid and, thus, can be priced higher by market makers to provide liquidity in the market as suggested in Deuskar, Gupta, and Subrahmanyam (2011). This also corresponds to the results in Table V. According to Battalio, Figlewski, and Neal (2020), the market bid prices of ITM American options are frequently below its intrinsic value, while the market ask prices are usually higher due to the existence of the intrinsic value. Thus, it can lead to a wide bid-ask spread for ITM American options. By contrast, DV illustrate an oppostie tendency across moneyness and maturity. This can be explained by the huge gap between the trading volume between OEX and XEO options as shown in Figure 2. Panel B of Table VI presents the average value of the liquidity of OEX options not smaller than that of the matched XEO options for each moneyness-maturity group. Almost all of the liquidity of all American options are significantly larger than that of European options. The average of *Spread* indicates that for OTM options with short-term maturity, American options are much more liquid than European options, which is in line with the preceding results. While in terms of DV, ATM American options are obviously more liquid. Overall, the findings in Table VI illustrate that OEX options are generally more liquid than matched XEO options.

[Insert Table VI about here.]

4.4 Regression Results

To test our second hypothesis, **H2**, we use a series of panel regression model to empirically evaluate the effects of the liquidity difference between OEX and XEO options on the EEP as well as the NEEP. The benchmark model is as follows:

$$\begin{aligned} EEP_{i,t} = \alpha + \beta_1 Spread_{i,t} + \beta_2 DV_{i,t} + \beta_3 Rf_{i,t} \\ + \beta_4 DY_{i,t} + \beta_5 Vol_{i,t} + \epsilon_{i,t}, \end{aligned} \quad (14)$$

$$NEEP_{i,t} = \alpha + \beta_1 Spread_{i,t} + \beta_2 DV_{i,t} + \beta_3 Rf_{i,t} + \beta_4 DY_{i,t} + \beta_5 Vol_{i,t} + \epsilon_{i,t}, \tag{15}$$

where $(N)EEP$ denotes the (N)EEP of the matched options. *Spread* and DV measures the liquidity difference in bid-ask spreads and trading volume in dollars. The remainings are control variables. Rf is the risk-free rate and DY is dividend yield. Vol is the volatility of the S&P 100 Index. In addition, we control for fixed effect in the regression, and the results of the regression are listed in Table VII. We first list the univariate regression results of the main sample period, then multiple regression results.

From Table VII, it is obvious that the liquidity indicators are statistically and economically significant for all EEP. Based on the estimations of column 6, when other variables remain the same, EEP will drop 0.038 or 0.354 if *Spread* or DV increase by a unit, respectively. The results indicate that the liquidity differences also explain the premium differences, i.e., the EEP, between American and European options written on the same equity index to a certain extent, which extends the earlier results of Deuskar, Gupta, and Subrahmanyam (2011) beyond the OTC derivative markets, and strongly supports **H2b**. The EEP of American options can drop with the increasing American liquidity or decreasing European liquidity.

As for $NEEP$, the explanatory power of *Spread* decreases dramatically, since the sign of coefficients of *Spread* is always positive yet insignificant. While all coefficients of DV are significantly negative, this suggests that there is a liquidity discount in the S&P 100 Index options market. As relatively lliquid options, OEX options will be priced by the market more accurately with less NEEP since there should be no NEEP in the market. However, the negative sign of the two liquidity measures indicates that the absolute value of the NEEP will be larger once American options are more liquid or European options are less liquid. Therefore, there should be an overvaluation of illiquid XEO options in the S&P 100 Index options market, which can lead to the market bid of a European option and, especially, ask prices being higher than the otherwise identical OEX options mentioned in preceding paragraphs. This finding enhance the argument of Deuskar, Gupta, and Subrahmanyam (2011) that the effect of liquidity on asset pricing cannot be generalized without regard to the features of the market. For control variables, the coefficients of Rf are still negative compared with EEP, but they are more significant, while DY is always significant but the sign is totally different. There is a significantly negative association between the volatility of the underlying index, Vol, and $NEEP$, but a significantly positive relationship with EEP.

[Insert Table VII about here.]

4.5 The Sources of the EEP

Given the NEEP of American options in the S&P 100 options market, which breaches the theory, this paper is designed to reveal it. However, it is essential to duly identify the sources which contribute to the premium of the right of early-exercise first, then, compare the remaining value between American and European options with less influence of the EEP. In this paper, we mainly account for the EEP from the Black-Scholes world, which is EBD defined in Section 3. However, before subtracting it from the original EEP, we attempt to investigate whether there exists TCS in the S&P 100 Index options market.

Since investors are more likely to exercise an option early if its time value is impaired, the factors that can potentially undermine the time value should be considered. For instance, high option moneyness, short maturity, and, particularly, wide bid–ask spreads. Then, following Battalio, Figlewski, and Neal (2020), TCS, which is economized from liquidating an ITM American option by exercising to recover its intrinsic value instead of selling at the lower market bid price, is reported in Table VIII. From Panel A of Table VIII, it is clear that the situation of intrinsic value of an OEX call option larger than its market bid is quite common in short maturity groups, and the percentage is highest in DITM with one-month expiration at 9.820%, which is in line with Battalio, Figlewski, and Neal (2020). This means that it is more optimal for the option holder to exercise early rather than sell it in the market when the holder has to liquidate the position. Panel B of Table VIII also displays similar results. Besides, the proportion of TCS of put options is higher than that of calls, but the savings are slightly smaller. In our sample, we can see that the cost savings are substantial, with the highest of 0.541% of the corresponding S&P 100 Index level, which can expound the lower percentages in ITM groups in Table V.

[Insert Table VIII about here.]

Then, we investigate how this phenomenon forms in the S&P 100 Index options market. Based on the definition of TCS, it only occurs when the market bid price is too low for an American option holder to liquidate the position through sell the option comared with early-exercise. Then, $Spread$ is supposed to affect it since an extreme lower market bid price can lead to a wide bid-ask spread. Therefore, TCS should be associated with the liquidity of the option. Since there is no TCS for most options, we execute an OLS regression to examine the effects, and the model is as follows:

$$TCS = \alpha + \beta_1 Spread + \beta_2 DV + \beta_3 Rf + \beta_4 DY + \beta_5 Vol + \epsilon. \tag{16}$$

The results are listed in Table IX, and it is clear that the coefficients of $Spread$ are all significantly negative, indicating that TCS will decrease if the American option is more liquid. Although the coefficients of DV are all insignificant, their sign is also negative, suggesting more liquid American options will be less likely to appear the TCS issue, which is in line with its economical explanatory power. Moreover, there is a significantly positive relationship between Vol and TCS. This is reasonable since if the underlying is more volatile, the value of optionality will be higher and might enhance the moneyness of the option.

[Insert Table IX about here.]

The other component of the EEP in the S&P 100 Index options market is EBD, discussed in Section 2 and Section 3. The results in Table X illustrate that the values are significant for all options. It is obvious that the EBD of calls can be greater than that of puts, especially for options with longer maturity. After identifying the value of the EEP from the Black-Scholes world, we then further compute the remaining EEP via subtracting EBD from the original EEP.

[Insert Table X about here.]

4.6 The Overvalued Phenomenon of Illiquid XEO Options

Since this paper mainly accounts for the EEP from the Black-Scholes world and compare the remaining value between OEX and XEO options to further investigate the overvalued phenomenon of European options, the EEP from other sources like TCS and the WC premium are not considered. Therefore, we still expect that American options are more valuable under this circumstance. Compared with Table III, Table XI clearly shows that cases of the NEEP are more frequent after controlling EBD. Besides, averages of the overvaluation are listed in the parentheses.

[Insert Table XI about here.]

Then, we also regress the liquidity measures on the remaining EEP as well as the negative remaining EEP as follows:

$$\begin{aligned} Remain_{i,t} = \alpha + \beta_1 Spread_{i,t} + \beta_2 DV_{i,t} + \beta_3 Rf_{i,t} \\ + \beta_4 DY_{i,t} + \beta_5 Vol_{i,t} + \epsilon_{i,t}, \end{aligned} \quad (17)$$

$$\begin{aligned} NRemain_{i,t} = \alpha + \beta_1 Spread_{i,t} + \beta_2 DV_{i,t} + \beta_3 Rf_{i,t} \\ + \beta_4 DY_{i,t} + \beta_5 Vol_{i,t} + \epsilon_{i,t}. \end{aligned} \quad (18)$$

The results are displayed in Table XII. It can be easily seen that all coefficients of the two liquidity measures are significantly negative in *Remain*, which is in line with the results in Table VII, supporting **H2b**. Moreover, the explanatory power of *Spread* significantly increases after accounting for EBD compared with Table VII. Although the coefficients are still insignificant in column 7 and 9, their signs are both negative, which is consistent with the economic explanation. While for DV, the coefficients are more significant after the subtraction of the EEP from the Black-Scholes world. Overall, the $NRemain$ will be more negative with the liquidity of American options increases, indicating that the premium gap between OEX and XEO options will be larger if American options are more liquid or European options are more illiquid.

[Insert Table XII about here.]

4.7 Robustness Tests

Several robustness tests have been conducted to check the robustness. First, for positive EEP and remaining EEP, we employ two alternative variables to measure the liquidity of the options. Open interest (OI) and turnover ratio (TO) are also regarded as the measures of liquidity by several studies (Li and Zhang, 2011; Battalio, Figlewski, and Neal, 2020; Jin, Zhao, and Luo, 2022), which can denote the preference of investors. Following previous studies, we define OI as the difference of the daily open interest of OEX and equivalent XEO options

$$OI_{i,t} = AmericanOI_{i,t} - EuropeanOI_{i,t}. \tag{19}$$

We use the turnover ratio, the frequency of a share changing hands within a given period, to scale resiliency. The reciprocal of the turnover ratio is usually interpreted as the average holding period by investors. For options, however, some modifications are needed because the outstanding amount changes over time, unlike the case of stocks and bonds. We define the turnover difference, TO, as

$$TO_{i,t} = \ln\left(1 + AmericanTO_{i,t}\right) - \ln\left(1 + EuropeanTO_{i,t}\right), \tag{20}$$

where

$$AmericanTO_{i,t} = \frac{AmericanTradingVolume_{i,t} - AmericanNewlyIssued_{i,t}}{AmericanOI_{i,t+1}}, \tag{21}$$

$$EuropeanTO_{i,t} = \frac{EuropeanTradingVolume_{i,t} - EuropeanNewlyIssued_{i,t}}{EuropeanOI_{i,t+1}}. \tag{22}$$

However, we do not have information on the amount of trading by option market makers. We assume that all the trades are between investors and, therefore, the turnover ratio of options defined this way may overestimate the actual turnover ratio. Table XIII shows the liquidity differences of OEX and XEO options based on the two new alternative measures. Likewise, OI and TO indicate OEX options are familiarly more liquid in the S&P 100 Index options market, which is in consistent with results in Table VI.

[Insert Table XIII about here.]

Similarly, we re-estimate the benchmark model of the original EEP with the two new alternative liquidity measures, OI and TO, and Table XIV reports the results. Obviously, all coefficients of the two liquidity measures are significantly negative, indicating a strong impact of liquidity on the option premium. Other control variables remain the same sign as well as significance compared with results in Table VII and Table XII.

[Insert Table XIV about here.]

Then, for $NRemain$ we re-estimate the model of the negative remaining EEP across moneyness and maturity groups since the results of different moneyness-maturity groups indicate distinct differences in preceding tables. Table XV reports that the two liquidity measures, $Spread$ and DV, are generally negatively correlated to the $NRemain$, suggesting that XEO options are overpriced in the S&P 100 Index options market due to illiquidity. Besides, the coefficients of $Spread$ will be insignificant in OTM, ATM, ITM, and DITM groups. It is reasonable since the bid-ask spread of an option is correlated to its moneyness. The bid-ask spread of a DITM call will be larger than that of an otherwise identical DOTM call. Besides, DV is significantly positive in ITM and DITM groups since the trading volumes between OEX and XEO options of these two groups are almost the same at zero. Therefore, OEX options may also suffer the overpriced issue in this group due to illiquidity, leading to the positive signs. As for maturity groups, it is more reasonable compared to moneyness group. Overall, it is clear that our empirical results are robust.

[Insert Table XV about here.]

5 Conclusion

This paper investigates the EEP of American options compared with the otherwise identical European options written on the same equity index, the S&P 100 Index. Previous studies (e.g., Jensen and Pedersen, 2016; Battalio, Figlewski, and Neal, 2020; Figlewski, 2022) analyze the EEP using individual equity option data, which are only American options, leading to an indirect observation of the EEP. Other literature employing the index option data are also subject to some limitations (e.g., McMurray and Yadav, 2000; Dueker and Miller Jr, 2003; Cao and Yadav, 2021). Using the unique feature of the S&P 100 Index options market, which trades both American and European options, we can directly obtain the market premium differences.

Our results demonstrate that American options are generally more expensive than European options in the S&P 100 Index options market, which is consistent with the conventional theory as well as extant literature. However, there is an overvauled phenomenon of European options that the midquote of a XEO option is higher than that of its OEX counterparts, i.e., the NEEP, leading to an instant arbitrage opportunity. Although this opportunity almost vanishes after considering market frictions like bid-ask spreads, the NEEP still exists when we compare the best available bid and ask prices of OEX and XEO options. Given this, we try to explain it using the liquidity of the options.

We first regress the observed market EEP and NEEP on the liquidity proxies measured by the bid-ask spreads and trading volume in dollars. Then, after duly accounting for the EEP from the Black-Scholes world, we re-estimate the regression based the remaining EEP and negative remaining EEP. Our results demonstrate that the liquidity difference significantly explains the overpricing phenomenon of illiquid options in the options market. The coefficients of the liquidity indicators are negative, and statistically and economically significant. This finding indicates that there is a liquidity discount in the S&P 100 Index options market, a European option can be mispriced with a higher market offer when its liquidity is less than an otherwise identical American option. This might be the compensation required by the market makers for providing liquidity in the market. Besides, this finding supports the argument of Deuskar, Gupta, and Subrahmanyam (2011) that the effect of liquidity on asset prices cannot be generalized without regard to the features of the market, and extends the study by providing evidence in equity index option market.

However, due to the availability of data, this paper is limited in several dimensions. First, more overvalued situations might be considered if employing the intraday data. Then, as documented in previous literature (e.g., Deuskar, Gupta, and Subrahmanyam, 2011; Battalio, Figlewski, and Neal, 2020; Jin, Zhao, and Luo, 2022), the trading details like buy, sell, and exercise behavior, which can reflect the rationality of investors as well as the inventory risk of liquidity providers, pose great influences on the EEP in derivative markets. Third, since we employ the bid-ask spreads as a liquidity proxy, it is more appropriate to measure the effective bid-ask spread in the option market. Future studies can contribute to this field by removing these limitations.

References

Amihud, Yakov, 2002, Illiquidity and stock returns: Cross-section and time-series effects, *Journal of Financial Markets* 5(1), 31–56.

Amihud, Yakov, and Haim Mendelson, 1986, Asset pricing and the bid-ask spread, *Journal of Financial Economics* 17(2), 223–249.

Amin, Kaushik I., and James N. Bodurtha Jr, 1995, Discrete-time valuation of American options with stochastic interest rates, *Review of Financial Studies* 8(1), 193–234.

Andricopoulos, Ari D., Martin Widdicks, Peter W. Duck, and David P. Newton, 2003, Universal option valuation using quadrature methods, *Journal of Financial Economics* 67(3), 447–471.

Andricopoulos, Ari D., Martin Widdicks, David P. Newton, and Peter W. Duck, 2007, Extending quadrature methods to value multi-asset and complex path dependent options, *Journal of Financial Economics* 83(2), 471–499.

Barone-Adesi, Giovanni, and Robert E. Whaley, 1986, The valuation of American call options and the expected ex-dividend stock price decline, *Journal of Financial Economics* 17(1), 91–111.

Barone-Adesi, Giovanni, and Robert E. Whaley, 1987, Efficient analytic approximation of American option values, *Journal of Finance* 42(2), 301–320.

Barraclough, Kathryn, and Robert E. Whaley, 2012, Early exercise of put options on stocks, *Journal of Finance* 67(4), 1423–1456.

Bates, David S., 1996, Jumps and stochastic volatility: Exchange rate processes implicit in Deutsche mark options, *Review of Financial Studies* 9(1), 69–107.

Battalio, Robert, Stephen Figlewski, and Robert Neal, 2020, Option investor rationality revisited: The role of exercise boundary violations, *Financial Analysts Journal* 76(1), 82–99.

Black, Fischer, and Myron Scholes, 1973, The pricing of options and corporate liabilities, *Journal of Political Economy* 81(3), 637–654.

Brennan, Michael J., and Eduardo S. Schwartz, 1977, The valuation of American put options, *Journal of Finance* 32(2), 449–462.

Brenner, Menachem, Rafi Eldor, and Shmuel Hauser, 2001, The price of options illiquidity, *Journal of Finance* 56(2), 789–805.

Broadie, Mark, Mikhail Chernov, and Michael Johannes, 2007, Model specification and risk premia: Evidence from futures options, *Journal of Finance* 62(3), 1453–1490.

Broadie, Mark, and Jerome Detemple, 1995, American capped call options on dividend-paying assets, *Review of Financial Studies* 8(1), 161–191.

Broadie, Mark, and Jerome Detemple, 1996, American option valuation: New bounds, approximations, and a comparison of existing methods, *Review of Financial Studies* 9(4), 1211–1250.

Bunch, David S., and Herb Johnson, 1992, A simple and numerically efficient valuation method for American puts using a modified Geske-Johnson approach, *Journal of Finance* 47(2), 809–816.

Bunch, David S., and Herb Johnson, 2000, The American put option and its critical stock price, *Journal of Finance* 55(5), 2333–2356.

Cao, Wenbin, and Pradeep K. Yadav, 2021, What is the value of being American? *Available at SSRN 4002837*.

Carr, Peter, 1998, Randomization and the American put, *Review of Financial Studies* 11(3), 597–626.

Carr, Peter, Robert Jarrow, and Ravi Myneni, 1992, Alternative characterizations of American put options, *Mathematical Finance* 2(2), 87–106.

Chance, Don M., and Roberts Brooks, 2015, *Introduction to derivatives and risk management*. Cengage Learning.

Chen, Ding, Hannu J. Härkönen, and David P. Newton, 2014, Advancing the universality of quadrature methods to any underlying process for option pricing, *Journal of Financial Economics* 114(3), 600–612.

Christoffersen, Peter, Ruslan Goyenko, Kris Jacobs, and Mehdi Karoui, 2018, Illiquidity premia in the equity options market, *Review of Financial Studies* 31(3), 811–851.

Cox, John C., 1985, *Options markets*. Englewood Cliffs, N.J: Prentice-Hall.

Cox, John C., Stephen A. Ross, and Mark Rubinstein, 1979, Option pricing: A simplified approach, *Journal of Financial Economics* 7(3), 229–263.

Deuskar, Prachi, Anurag Gupta, and Marti G. Subrahmanyam, 2011, Liquidity effect in OTC options markets: Premium or discount? *Journal of Financial Markets* 14(1), 127–160.

Duan, Jin-Chuan, 1995, The GARCH option pricing model, *Mathematical Finance* 5(1), 13–32.

Dueker, Michael, and Thomas W. Miller Jr, 2003, Directly measuring early exercise premiums using American and European S&P 500 index options, *Journal of Futures Markets* 23(3), 287–313.

Dueker, Michael J., and Thomas W. Miller Jr, 1996, Market microstructure effects on the direct measurement of the early exercise premium in exchange-listed options, *Federal Reserve Bank of St. Louis Working Paper Series* (1996-013).

Figlewski, Stephen, 2022, An American call is worth more than a European call: The value of American exercise when the market is not perfectly liquid, *Journal of Financial and Quantitative Analysis* 57(3), 1023–1057.

Finucane, Thomas J., 1997, An empirical analysis of common stock call exercise: A note, *Journal of Banking & Finance* 21(4), 563–571.

Fleming, Jeff, and Robert E. Whaley, 1994, The value of wildcard options, *Journal of Finance* 49(1), 215–236.

Geske, Robert, 1979, A note on an analytical valuation formula for unprotected American call options on stocks with known dividends, *Journal of Financial Economics* 7(4), 375–380.

Geske, Robert, and Herb E. Johnson, 1984, The American put option valued analytically, *Journal of Finance* 39(5), 1511–1524.

Geske, Robert, and Richard Roll, 1984, On valuing American call options with the Black-Scholes European formula, *Journal of Finance* 39(2), 443–455.

Huang, Jing-zhi, Marti G. Subrahmanyam, and G. George Yu, 1996, Pricing and hedging American options: A recursive integration method, *Review of Financial Studies* 9(1), 277–300.

Hull, John C, 2003, *Options futures and other derivatives*. Pearson Education India.

Jacka, Saul D., 1991, Optimal stopping and the American put, *Mathematical Finance* 1(2), 1–14.

Jensen, Mads Vestergaard, and Lasse Heje Pedersen, 2016, Early option exercise: Never say never, *Journal of Financial Economics* 121(2), 278–299.

Jin, Xuejun, Jingyu Zhao, and Xingguo Luo, 2022, Why are the prices of European-style derivatives greater than the prices of American-style derivatives? *Journal of Futures Markets* 42(9), 1772–1793.

Ju, Nengjiu, 1998, Pricing by American option by approximating its early exercise boundary as a multipiece exponential function, *Review of Financial Studies* 11(3), 627–646.

Kim, In Joon, 1990, The analytic valuation of American options, *Review of Financial Studies* 3(4), 547–572.

Lasser, Dennis J., and Joshua D. Spizman, 2016, The value of the wildcard option in cash-settled American index options, *Journal of Financial Markets* 28, 116–131.

Lee, Jae Ha, and Nandkumar Nayar, 2000, *Can the American option sell for less than the matched European option?* Tech. rep. Working Paper, Norman: The University of Oklahoma.

Leippold, Markus, and Steven Schärer, 2017, Discrete-time option pricing with stochastic liquidity, *Journal of Banking & Finance* 75, 1–16.

Li, Gang, and Chu Zhang, 2011, Why are derivative warrants more expensive than options? An empirical study, *Journal of Financial and Quantitative Analysis* 46(1), 275–297.

Longstaff, Francis A., and Eduardo S. Schwartz, 2001, Valuing American options by simulation: A simple least-squares approach, *Review of Financial Studies* 14(1), 113–147.

McDonald, Robert L. (Robert Lynch), 2013, *Derivatives markets*. Pearson new international edition, Third edition. Harlow, Essex, England: Pearson Education.

McMurray, Lindsey, and Pradeep K. Yadav, 2000, The early exercise premium in American option prices: Direct empirical evidence, *Available at SSRN 7110*.

Medvedev, Alexey, and Olivier Scaillet, 2010, Pricing American options under stochastic volatility and stochastic interest rates, *Journal of Financial Economics* 98(1), 145–159.

Merton, Robert C., 1973, Theory of rational option pricing, *Bell Journal of Economics and Management Science*, 141–183.

Nelson, Daniel B., and Krishna Ramaswamy, 1990, Simple binomial processes as diffusion approximations in financial models, *Review of Financial Studies* 3(3), 393–430.

Newey, Whitney K., and Kenneth D. West, 1986, A simple, positive semi-definite, heteroskedasticity and autocorrelationconsistent covariance matrix, *IDEAS Working Paper Series from RePEc*.

Pool, Veronika Krepely, Hans R. Stoll, and Robert E. Whaley, 2008, Failure to exercise call options: An anomaly and a trading game, *Journal of Financial Markets* 11(1), 1–35.

Poteshman, Allen M., and Vitaly Serbin, 2003, Clearly irrational financial market behavior: Evidence from the early exercise of exchange traded stock options, *Journal of Finance* 58(1), 37–70.

Ritchken, Peter, and Rob Trevor, 1999, Pricing options under generalized GARCH and stochastic volatility processes, *Journal of Finance* 54(1), 377–402.

Roll, Richard, 1977, An analytic valuation formula for unprotected American call options on stocks with known dividends, *Journal of Financial Economics* 5(2), 251–258.

Rubinstein, Mark, 1994, Implied binomial trees, *Journal of Finance* 49(3), 771–818.

Schwartz, Eduardo S., 1977, The valuation of warrants: Implementing a new approach, *Journal of Financial Economics* 4(1), 79–93.

Sullivan, Michael A., 2000, Valuing American put options using Gaussian quadrature, *Review of Financial Studies* 13(1), 75–94.

Whaley, Robert E., 1981, On the valuation of American call options on stocks with known dividends, *Journal of Financial Economics* 9(2), 207–211.

Whaley, Robert E., 1982, Valuation of American call options on dividend-paying stocks: Empirical tests, *Journal of Financial Economics* 10(1), 29–58.

Whaley, Robert E., 1986, Valuation of American futures options: Theory and empirical tests, *Journal of Finance* 41(1), 127–150.

Appendix

A Literature on Pricing American Options

This is how the price of American options has been widely documented by researchers in the last 30 years of last century. By approximating the Black-Scholes PDE via finite differences, Brennan and Schwartz (1977) derive the numerical solution technique to evaluate American puts and find that the model prices indicate substantial arbitrage opportunities. However, Schwartz (1977) shows that the Black-Scholes model without constant dividend yield is more exact at pricing American warrants. In the same year, Roll (1977) demonstrates how to value an early exercised American call using three European options, which is simplified by Geske (1979) by introducing the compound option. The well-known binomial tree model has been forwarded by Cox, Ross, and Rubinstein (1979). Whaley (1981) argues that the exercise price is misspecified in the equations of both Roll (1977) and Geske (1979), and then, employing the corrected valuation formula to price American calls, Whaley (1982) finds that it is more suitable for the observed structure of call prices. Geske and Roll (1984) find that the near-maturity American options are undervalued by the Black and Scholes (1973) model. Geske and Johnson (1984) then display a new analytic expression to price American put options subject to free boundary condition based on the method used in Geske (1979). Barone-Adesi and Whaley (1986) find that the approaches in Roll (1977), Geske (1979), and Whaley (1981) are applicable to the American calls to forecast the decrease in stocks. In the same year, Whaley (1986) illustrates that the S&P 500 futures option market is not efficient during the sample period via the American options pricing model developed by Barone-Adesi and Whaley (1987).

In addition, Nelson and Ramaswamy (1990) combine the constant elasticity of variance (CEV) diffusion in Cox (1985) and the binomial model in Cox, Ross, and Rubinstein (1979) to price the American options. Kim (1990) states that the value of an American put should be the same as the market price of the corresponding European put and an integral indicating the EEP. With quadrivariate normal integrals, Bunch and Johnson (1992) show another analytical solution for American puts following Geske (1979) and Geske and Johnson (1984). In Rubinstein (1994), the author compares the property differences between European and American options through a new method for inferring risk-neutral probabilities from the simultaneously observed prices. Also employing the binomial tree model developed in Cox, Ross, and Rubinstein (1979), Amin and Bodurtha Jr (1995) develop an arbitrage-free discrete time model to price American claims. According to Kim (1990), Broadie and Detemple (1995) analyze how to value the American options with constant caps and caps with a constant growth. In addition, the authors show the lower and upper bounds of American option market prices in Broadie and Detemple (1996). Besides, recursive implementation is used in Huang, Subrahmanyam, and Yu (1996), stochastic volatility and jump-diffusion processed are considered in Bates (1996), and randomization technique is applied in Carr (1998). By approximating the early exercise boundary of an American option as a multipiece exponential function, Ju (1998) presents a closed form formula following Kim (1990), Jacka (1991), and Carr, Jarrow, and

Myneni (1992). Ritchken and Trevor (1999) modifies the GARCH model in Duan (1995) via an efficient lattice algorithm.

Besides, through combining numerical integration using Gaussian quadrature and function approximation using Chebyshev polynomials, Sullivan (2000) can estimate the valuation of American options. Bunch and Johnson (2000) first yield intuition for the perpetual put and then examine the finite-lived case using equation obtained by Kim (1990), Jacka (1991), Carr, Jarrow, and Myneni (1992), and Huang, Subrahmanyam, and Yu (1996). Then, Longstaff and Schwartz (2001) forward an approach, known as the least-square Monte Carlo simulation, which has been widely applied to price American options. Then, Andricopoulos et al. (2003) first adapt the Black-Scholes PDE with quadrature methods, and hold that it possesses exceptional accuracy and speed when pricing American calls. Andricopoulos et al. (2007) then extend the method by considering American calls with discrete dividends, and Chen, Härkönen, and Newton (2014) further improved the quadrature method. Based on the affine jump diffusion model, Broadie, Chernov, and Johannes (2007) show how to simplify the computation by transforming American option prices to European ones. Medvedev and Scaillet (2010) introduce a new analytical approach to price American options via a short-maturity asymptotic expansion. Overall, as Table A.1 shows that how to price American options has been studied for several decades, and has developed various methods to address the problem, which are applied in a number of empirical studies.

[Insert Table A.1 about here.]

Tables

Table I: Summary Statistics.
This table reports the descriptive statistics for the variables we construct in Section 3. We winsorize all variables at the 1% and 99%. $(N)EEP$ denotes the (N)EEP of the matched options. $(N)Remain$ denotes the negative remaining EEP of the matched options after duly accounting for two sources of market EEP. $Spread$ and DV measures the liquidity difference in bid-ask spreads and trading volume in dollars. The remainings are control variables. Rf is the risk-free rate and DY is dividend yield, which can affect the early-exercise decision of market participants. Vol is the implied volatility of S&P 100 Index. The sample period is from 23 July 2001 to 31 December 2010, when the S&P 100 Index options market is relatively liquid.

Variable	Mean	St. Dev.	Min	Median	Max	N
EEP	0.073	0.084	-0.029	0.042	0.422	218,068
$Remain$	0.059	0.070	-0.066	0.035	0.345	218,066
$NEEP$	-0.016	0.016	-0.123	-0.010	-0.004	17,093
$NRemain$	-0.019	0.034	-0.266	-0.008	0	30,185
$Spread$	0.040	0.113	-0.168	0.005	0.842	218,067
DV	0.047	0.106	-0.405	0.005	0.588	218,126
Rf	1.864	1.630	0.016	1.550	5.178	218,073
DY	1.830	0.443	0.491	1.957	2.771	218,125
Vol	0.035	0.021	0.012	0.030	0.140	217,894

Table II: Description of Premiums OEX and XEO Options.
Panel A reports the number of observations of matched options. Panel B and Panel C report the 100 times OEX and XEO option premium scaled by the underlying, S&P 100 Index, respectively. Panel D reports the Newey and West (1986) test results for the premium difference between the two options, EEP, across different moneyness and maturity groups. The sample period is from 23 July 2001 to 31 December 2010, when the S&P100 Index options market is relatively liquid. * indicates an insignificant difference from 0 at the 5% level.

	Call						Put					
Group	7–30	30–60	60–120	120–180	180–360	Total	7–30	30–60	60–120	120–180	180–360	Total
Panel A: Number of Observations of Matched Options												
DOTM	1,186	3,414	3,799	1,742	1,881	25,843	5,744	11,618	8,635	2,458	2,413	30,868
OTM	7,513	13,053	8,694	2,397	2,009	33,407	12,425	16,260	9,010	2,591	2,201	42,487
ATM	7,047	7,629	4,423	1,260	1,036	22,750	7,069	7,691	4,321	1,344	1,171	21,596
ITM	8,264	7,404	4,181	1,758	2,009	8,059	6,703	6,721	3,953	1,673	1,532	20,582
DITM	1,833	1,907	1,653	902	1,423	8,358	2,184	2,281	1,909	1,047	1,145	8,566
Total	25,843	33,407	22,750	8,059	8,358	98,417	34,125	44,571	27,828	9,113	8,462	124,099
Panel B: Premiums of OEX Options												
DOTM	0.249	0.426	0.702	1.041	1.558	0.762	0.214	0.413	0.851	1.476	2.198	0.723
OTM	0.441	0.794	1.444	2.497	3.659	1.175	0.480	1.002	1.850	3.141	4.147	1.322
ATM	1.636	2.494	3.592	5.058	6.508	2.784	1.672	2.537	3.657	4.822	5.924	2.804
ITM	5.841	6.440	7.432	8.923	10.249	6.915	5.685	6.254	7.432	8.683	9.699	6.749
DITM	13.938	14.584	15.528	16.192	17.069	15.279	14.505	14.999	15.672	16.090	17.305	15.465
Total	3.442	3.183	3.862	5.517	7.406	3.958	2.602	2.621	3.562	5.445	6.623	3.307
Panel C: Premiums of XEO Options												
DOTM	0.245	0.413	0.679	1.012	1.516	0.740	0.209	0.404	0.832	1.448	2.170	0.708
OTM	0.430	0.772	1.407	2.441	3.576	1.146	0.468	0.977	1.807	3.080	4.077	1.293
ATM	1.597	2.438	3.515	4.964	6.386	2.724	1.620	2.466	3.566	4.708	5.793	2.729
ITM	5.720	6.313	7.295	8.767	10.073	6.782	5.520	6.079	7.235	8.476	9.479	6.567
DITM	13.724	14.340	15.269	15.906	16.764	15.023	14.260	14.732	15.384	15.788	16.922	15.179
Total	3.374	3.118	3.785	5.414	7.268	3.880	2.538	2.558	3.480	5.330	6.487	3.231
Panel D: Premium Difference Between OEX and XEO Options												
DOTM	0.004	0.013	0.023	0.028	0.041	0.022	0.005	0.009	0.019	0.028	0.028	0.014
OTM	0.011	0.022	0.037	0.057	0.083	0.029	0.012	0.025	0.043	0.061	0.069	0.029
ATM	0.038	0.056	0.076	0.094	0.123	0.060	0.052	0.071	0.091	0.114	0.132	0.075
ITM	0.122	0.127	0.137	0.156	0.176	0.133	0.164	0.175	0.197	0.207	0.220	0.182
DITM	0.214	0.244	0.259	0.287	0.305	0.256	0.245	0.267	0.288	0.302	0.382	0.286
Total	0.068	0.065	0.077	0.104	0.139	0.078	0.064	0.064	0.082	0.114	0.136	0.076

Table III: The Negative Early Exercise Premium Phenomenon and Instant Arbitrage Opportunities.

This table reports the percentages of the NEEP phenomenon of the S&P 100 Index options. Case 1 stands for the EEP that OEX options are more expensive than the otherwise identical XEO options. Case 2 stands for the same value of OEX and XEO options. Case 3 stands for the NEEP that XEO options are more expensive than the otherwise identical OEX options. The averages are reported in parentheses. The sample period is from 23 July 2001 to 31 December 2010, when the S&P 100 Index options market is relatively liquid.

		Call						Put					
Group	Case	7-30	30-60	60-120	120-180	180-360	Total	7-30	30-60	60-120	120-180	180-360	Total
DOTM	1	52.445	69.566	76.494	77.669	81.021	73.033	53.412	62.429	75.437	82.465	80.854	67.426
		(0.020)	(0.023)	(0.033)	(0.040)	(0.054)	(0.034)	(0.014)	(0.018)	(0.027)	(0.036)	(0.037)	(0.024)
	2	16.442	17.018	12.372	7.003	7.443	12.544	23.433	20.959	15.808	10.130	9.905	18.252
		(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)
	3	31.113	13.415	11.135	15.327	11.536	14.424	23.155	16.612	8.755	7.404	9.242	14.322
		(-0.019)	(-0.017)	(-0.017)	(-0.018)	(-0.019)	(-0.018)	(-0.013)	(-0.012)	(-0.015)	(-0.022)	(-0.025)	(-0.014)
OTM	1	65.407	77.300	85.829	90.655	93.529	78.768	67.678	80.996	92.741	95.986	94.866	81.225
		(0.022)	(0.031)	(0.044)	(0.064)	(0.089)	(0.040)	(0.022)	(0.032)	(0.047)	(0.064)	(0.074)	(0.038)
	2	13.763	9.844	6.671	3.338	3.086	9.033	13.264	9.766	4.173	2.123	1.408	8.704
		(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)
	3	20.831	12.855	7.499	6.008	3.385	12.199	19.058	9.237	3.085	1.891	3.726	10.071
		(-0.015)	(-0.015)	(-0.017)	(-0.027)	(-0.024)	(-0.016)	(-0.013)	(-0.014)	(-0.021)	(-0.047)	(-0.032)	(-0.014)
ATM	1	80.119	90.785	95.388	94.524	95.077	88.652	87.622	96.424	98.982	98.735	98.207	94.295
		(0.052)	(0.064)	(0.081)	(0.102)	(0.130)	(0.070)	(0.061)	(0.075)	(0.092)	(0.116)	(0.135)	(0.080)
	2	6.215	3.316	1.673	1.429	1.062	3.711	4.187	1.755	0.417	0.149	0.256	2.102
		(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)
	3	13.665	5.899	2.939	4.048	3.861	7.637	8.191	1.820	0.602	1.116	1.537	3.603
		(-0.022)	(-0.026)	(-0.027)	(-0.045)	(-0.031)	(-0.024)	(-0.022)	(-0.038)	(-0.041)	(-0.066)	(-0.042)	(-0.027)
ITM	1	97.967	98.271	98.254	96.303	97.063	97.912	99.597	99.524	99.671	99.223	98.825	99.500
		(0.125)	(0.130)	(0.140)	(0.163)	(0.182)	(0.137)	(0.165)	(0.176)	(0.198)	(0.209)	(0.223)	(0.183)
	2	0.617	0.581	0.478	0.739	0.398	0.572	0.149	0.104	0.076	0.299	0.457	0.155
		(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)
	3	1.416	1.148	1.268	2.958	2.539	1.516	0.254	0.372	0.253	0.478	0.718	0.345
		(-0.055)	(-0.050)	(-0.031)	(-0.046)	(-0.033)	(-0.046)	(-0.107)	(-0.054)	(-0.066)	(-0.067)	(-0.056)	(-0.070)
DITM	1	99.073	99.371	99.758	99.667	98.876	99.326	99.954	99.868	99.790	99.618	99.563	99.802
		(0.217)	(0.246)	(0.259)	(0.289)	(0.309)	(0.259)	(0.245)	(0.268)	(0.288)	(0.303)	(0.385)	(0.286)
	2	0.055	0.105	0.000	0.000	0.141	0.065	0.046	0.044	0.052	0.000	0.087	0.047
		(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)
	3	0.873	0.524	0.242	0.333	0.984	0.609	0.000	0.088	0.157	0.382	0.349	0.152
		(-0.048)	(-0.046)	(-0.100)	(-0.391)	(-0.031)	(-0.069)	(0)	(-0.034)	(-0.034)	(-0.072)	(-0.21)	(-0.100)
Total	1	81.624	85.497	89.424	90.694	92.666	86.422	77.744	82.578	89.809	93.756	92.685	84.380
		(0.086)	(0.078)	(0.087)	(0.116)	(0.151)	(0.092)	(0.085)	(0.079)	(0.092)	(0.123)	(0.148)	(0.092)
	2	6.652	6.478	5.029	2.891	2.668	5.571	9.673	9.347	6.335	3.413	3.321	7.915
		(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)
	3	11.725	8.025	5.547	6.415	4.666	8.007	12.583	8.075	3.856	2.831	3.994	7.705
		(-0.019)	(-0.018)	(-0.019)	(-0.028)	(-0.023)	(-0.020)	(-0.014)	(-0.014)	(-0.017)	(-0.031)	(-0.031)	(-0.016)

Table IV: Instant Arbitrage Profit after Considering Bid-Ask Spreads.
This table reports the instant arbitrage profit after considering bid-ask spreads. TTM and M stand for time to maturity and moneyness, respectively. We also list daily trading volume and open interest of the option. Profit is directly computed by the difference of the market bid of a XEO option and the market offer of its counterpart OEX option. The sample period is from 23 July 2001 to 31 December 2010, when the S&P 100 Index options market is relatively liquid.

OEX				Date	Type	TTM	M	XEO				**Profit**
Open Interest	Volume	Ask	Bid					Bid	Ask	Volume	Open Interest	
6,127	255	0.25	0.10	27/09/2001	C	23	-0.150	0.35	0.60	-	1	**0.10**
7,975	3,793	1.80	1.60	31/07/2002	C	17	-0.068	1.95	2.25	24	301	**0.15**
5,890	352	2.10	2.05	31/07/2002	C	52	-0.133	2.20	2.65	-	1,118	**0.10**
1,117	30	1.30	1.25	31/07/2002	C	52	-0.155	1.45	1.75	-	11	**0.15**
11,773	5,201	4.40	4.30	10/10/2003	C	8	-0.004	4.50	5.10	336	11,640	**0.10**
15,991	4,602	7.10	6.80	10/09/2004	C	8	0.011	7.30	8.30	-	3,372	**0.20**
14,103	4,601	1.05	1.00	10/09/2004	C	8	-0.007	1.10	1.60	46	888	**0.05**
8,539	4,974	2.25	2.20	31/01/2006	C	18	-0.011	2.45	3.10	-	360	**0.20**
5,898	5,815	1.80	1.75	14/07/2006	C	8	-0.014	1.95	2.20	32	3,472	**0.15**
189	10	32.50	30.40	26/07/2007	C	23	0.043	32.90	37.10	-	98	**0.40**
33	5	28.60	26.50	26/07/2007	C	23	0.036	28.90	32.90	-	62	**0.30**
210	-	55.20	53.10	26/07/2007	C	58	0.072	55.80	60.30	-	31	**0.60**
536	3,829	100.10	98.00	26/07/2007	C	149	0.130	100.80	105.30	-	58	**0.70**
203	-	83.60	81.50	26/07/2007	C	149	0.101	83.90	88.40	-	13	**0.30**
2,793	2,081	6.20	5.90	11/01/2002	P	8	0.001	6.40	6.90	2,048	3,736	**0.20**
50	100	9.00	8.50	04/02/2002	P	138	-0.133	9.10	10.10	-	250	**0.10**
2,591	295	0.55	0.50	01/10/2002	P	18	-0.178	0.60	0.65	-	9	**0.05**
400	56	0.90	0.60	01/10/2002	P	18	-0.143	1.00	1.05	10	1	**0.10**
711	156	1.95	1.75	14/02/2003	P	36	-0.172	2.40	2.50	-	13	**0.45**
827	-	1.00	0.95	09/05/2003	P	43	-0.132	1.05	1.15	-	218	**0.05**
7,722	2,249	4.70	4.30	30/10/2003	P	23	-0.015	4.80	5.30	16	1,891	**0.10**
152	6	19.10	18.10	30/10/2003	P	23	0.034	19.20	20.20	-	10	**0.10**
9,196	2,125	4.80	4.50	28/05/2004	P	22	-0.009	5.00	5.20	3	3,829	**0.20**
51	-	62.10	60.10	03/06/2004	P	198	0.103	62.20	64.20	-	54	**0.10**
17	-	97.30	95.30	03/06/2004	P	198	0.177	97.50	99.50	-	1	**0.20**
9,633	1,387	3.00	2.70	26/09/2005	P	26	-0.013	3.10	3.60	35	384	**0.10**
11,389	2,607	4.10	3.90	26/09/2005	P	26	-0.004	4.50	5.00	24	2,368	**0.40**
7,752	3,387	6.10	5.50	26/09/2005	P	26	0.005	6.40	7.10	1,211	1,867	**0.30**
7,416	1,199	8.40	7.70	26/09/2005	P	26	0.014	8.90	9.60	30	8,139	**0.50**
16,359	5,599	0.85	0.80	14/10/2005	P	8	-0.019	0.90	1.20	1,432	3,182	**0.05**

Table V: Bid-Ask Spreads of OEX and XEO Options.
Panel A report the percentage of OEX bid less than XEO bid, and Panel B report the percentage of OEX offer less than XEO offer, respectively. The sample period is from 23 July 2001 to 31 December 2010, when the S&P 100 Index options market is relatively liquid.

	Call						Put					
Group	7–30	30–60	60–120	120–180	180–360	Total	7–30	30–60	60–120	120–180	180–360	Total
Panel A: Percentage of the NEEP of Market Bid Price												
DOTM	10.708	8.231	10.134	10.563	7.018	9.225	7.956	13.376	10.701	8.706	14.007	11.296
OTM	4.086	7.033	6.740	7.551	10.801	6.562	5.481	6.900	4.706	4.091	6.224	5.814
ATM	2.654	4.994	6.557	6.825	8.494	4.824	1.542	1.807	2.129	1.860	4.184	1.917
ITM	2.420	4.484	4.329	5.404	6.122	3.942	0.642	0.848	0.835	1.435	3.916	1.054
DITM	1.855	1.521	0.968	0.554	2.670	1.581	0.000	0.175	0.367	0.764	1.048	0.362
Total	3.308	5.810	6.409	6.837	7.155	5.490	3.780	6.453	5.318	4.137	7.043	5.334
Panel B: Percentage of the NEEP of Market Offer Price												
DOTM	54.384	25.132	15.609	22.273	20.468	23.865	39.746	23.395	13.248	12.286	14.878	22.049
OTM	48.463	22.623	12.399	11.556	6.521	24.000	42.366	16.316	6.770	5.905	7.633	20.825
ATM	33.972	12.924	5.404	6.905	6.371	17.630	25.633	7.294	3.055	3.125	4.355	12.030
ITM	5.966	4.484	3.875	5.290	4.231	4.933	3.521	2.366	1.796	1.973	3.264	2.667
DITM	2.728	1.573	1.270	2.882	1.195	1.866	0.962	1.534	0.681	1.146	2.096	1.226
Total	27.950	15.443	9.200	10.808	8.184	16.288	28.179	13.744	7.079	5.948	7.705	15.235

Table VI: Liquidity Differences.
This table shows the liquidity differences between OEX and XEO options in each moneyness-maturity group for calls and puts separately. DOTM, OTM, ATM, ITM, and DITM denote $-0.20 < M \leq -0.10$, $-0.10 < M \leq -0.02$, $-0.02 < M \leq 0.02$, $0.02 < M \leq 0.10$, and $0.10 < M \leq 0.20$. *Spread* and *DV* measure the liquidity differences in spread and trading volume in dollars. Subscripts OEX and XEO stand for OEX and XEO options, respectively. Panel A and B report the proportion and the average value of the OEX option liquidity measure, which are equal or greater than the values of the otherwise identical XEO option. The Newey and West (1986) test results of the average value of the OEX option liquidity measure larger than the matched XEO option liquidity measure are displayed. The sample period is from 23 July 2001 to 31 December 2010, when the S&P 100 Index options market is relatively liquid. * indicates an insignificant difference from 0 at the 5% level.

		Call						Put					
Liquidity	Group	7–30	30–60	60–120	120–180	180–360	Total	7–30	30–60	60–120	120–180	180–360	Total
Panel A: Proportion													
$Spread_{OEX} \leq Spread_{XEO}$	DOTM	87.099	82.191	76.573	78.473	79.851	79.995	87.134	75.237	72.368	74.125	69.208	76.089
	OTM	92.094	81.261	74.672	71.589	69.139	80.565	89.038	78.352	74.295	74.759	68.423	79.883
	ATM	88.761	78.372	70.382	70.159	65.927	79.056	89.079	79.509	71.095	70.833	62.596	79.501
	ITM	68.708	68.666	65.319	72.582	66.551	68.200	72.371	70.525	66.532	72.923	67.037	70.294
	DITM	63.666	62.087	65.880	73.060	61.279	64.408	63.141	68.216	69.041	72.779	65.677	67.324
	Total	81.461	76.810	71.798	73.235	69.191	75.933	83.795	76.040	71.737	73.445	67.218	76.416
$DV_{OEX} \geq DV_{XEO}$	DOTM	93.255	89.397	94.025	95.235	96.757	93.237	92.880	92.365	93.399	96.623	97.265	93.472
	OTM	96.313	91.328	91.028	94.743	96.765	92.931	96.539	91.335	90.910	95.562	97.138	93.325
	ATM	88.804	88.124	88.967	92.540	94.402	89.086	91.314	88.558	88.498	90.327	93.083	89.804
	ITM	92.764	93.287	94.092	96.985	96.715	93.814	93.316	91.861	93.499	94.023	97.258	93.227
	DITM	96.399	96.329	98.488	98.670	98.595	97.499	95.559	94.388	95.181	97.708	97.904	95.739
	Total	92.996	91.119	92.233	95.434	96.770	92.702	94.145	91.360	91.969	95.040	96.738	92.899
Panel B: Average													
$-(Spread_{OEX} - Spread_{XEO})$	DOTM	0.297	0.115	0.048	0.066	0.043	0.093	0.208	0.060	0.017	0.010	0.000*	0.067
	OTM	0.240	0.075	0.019	0.010	0.002	0.088	0.190	0.034	0.007	0.005	0.001	0.070
	ATM	0.058	0.013	0.002	0.003	0.001*	0.024	0.050	0.014	0.003	0.003	-0.001*	0.022
	ITM	0.004	0.002	0.001	0.002	0.001	0.002	0.006	0.005	0.002	0.003	0.001	0.004
	DITM	0.001	0.001	0.001	0.002	0.001	0.001	0.001	0.002	0.002	0.002	0.003	0.002
	Total	0.100	0.044	0.016	0.018	0.011	0.047	0.116	0.031	0.008	0.006	0.001	0.045
$(DV_{OEX} - DV_{XEO}) * 100$	DOTM	0.123	0.051	0.032	0.023	0.024	0.044	0.065	0.045	0.026	0.021	0.019	0.039
	OTM	0.453	0.139	0.057	0.073	0.129	0.182	0.379	0.153	0.080	0.068	0.054	0.193
	ATM	1.306	0.349	0.151	0.219	0.152*	0.606	1.645	0.347	0.114	0.107	0.004*	0.692
	ITM	0.472	0.223	0.125	0.206	0.056	0.277	0.523	-0.033*	0.082	0.068	0.018	0.182
	DITM	0.201	0.190	0.383	0.456	0.070*	0.243	0.277	0.235	0.187	0.046	0.038*	0.186
	Total	0.659	0.199	0.107	0.157	0.081	0.285	0.610	0.134	0.076	0.058	0.029	0.239

Table VII: Influence of Market Liquidity on Early Exercise Premium.
This table shows the regression estimates of EEP on liquidity of the market and other determinants. $(N)EEP$ denotes the (N)EEP of the matched options. *Spread* and DV measures the liquidity difference in bid-ask spreads and trading volume in dollars. The remainings are control variables. Rf is the risk-free rate and DY is dividend yield. Vol is the volatility of S&P 100 Index. The sample period is from 23 July 2001 to 31 December 2010, when the S&P 100 Index options market is relatively liquid. Newey and West (1986) $t-statistics$ are reported in the parentheses. *, ** and *** indicate significance at 10%, 5% and 1% level, respectively.

VARIABLES	*EEP*						*NEEP*					
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
Spread	-0.042***		-0.040***	-0.040***		-0.038***	0.001		0.001	0.000		0.000
	(-24.88)		(-24.55)	(-25.03)		(-24.56)	(1.23)		(1.10)	(0.64)		(0.54)
DV		-0.362***	-0.347***		-0.365***	-0.354***		-0.092**	-0.085**		-0.068*	-0.064*
		(-7.26)	(-7.08)		(-7.55)	(-7.43)		(-2.48)	(-2.30)		(-1.91)	(-1.77)
Rf				-0.000	0.001	-0.000				-0.003***	-0.003***	-0.003***
				(-0.14)	(0.30)	(-0.16)				(-4.95)	(-5.46)	(-5.09)
DY				-0.010***	-0.010***	-0.009***				0.003***	0.003***	0.003***
				(-3.63)	(-3.61)	(-3.44)				(3.69)	(4.03)	(3.95)
Vol				0.534***	0.519***	0.524***				-0.270***	-0.271***	-0.261***
				(6.55)	(6.37)	(6.39)				(-9.05)	(-8.99)	(-8.61)
Constant	0.082***	0.080***	0.083***	0.081***	0.078***	0.081***	-0.016***	-0.015***	-0.015***	-0.005*	-0.004	-0.005*
	(1,460.75)	(767.38)	(646.79)	(10.59)	(10.13)	(10.51)	(-208.65)	(-152.17)	(-115.93)	(-1.88)	(-1.58)	(-1.87)
Individual FE	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES
Observations	198,973	198,971	194,924	187,241	187,357	183,530	16,765	16,756	16,428	15,804	15,816	15,504
Adj R-squared	0.007	0.002	0.008	0.021	0.015	0.022	0.000	0.001	0.001	0.023	0.025	0.024

Table VIII: Transaction Cost Savings.
Panel A and Panel B report the proportion of intrinsic value larger than the market bid price of OEX calls and puts. The average saved transaction costs, TCS, are reported in parentheses times 100. We only report in-the-money options whose $Moneyness > 0$. The sample period is from 23 July 2001 to 31 December 2010, when the S&P 100 Index options market is relatively liquid.

Moneyness (M)	Time to Maturity (T)					
	7–30	30–60	60–120	120–180	180–360	Total
Panel A: Proportion of Intrinsic Value Larger than Bid of OEX Calls						
$0.00 < M \leq 0.02$	0.029	0	0	0	0	0.010
	(0.541)	.	.	.	.	(0.541)
$0.02 < M \leq 0.10$	3.400	0.176	0	0	0	1.245
	(0.055)	(0.049)	.	.	.	(0.055)
$0.10 < M \leq 0.20$	9.820	4.877	1.210	0.111	0	3.809
	(0.071)	(0.061)	(0.059)	(0.044)	.	(0.067)
Total	3.413	0.823	0.252	0.031	0	1.417
	(0.063)	(0.060)	(0.059)	(0.044)	.	(0.062)
Panel B: Proportion of Intrinsic Value Larger than Bid of OEX Puts						
$0.00 < M \leq 0.02$	0.917	0.028	0	0	0	0.321
	(0.039)	(0.182)	.	.	.	(0.043)
$0.02 < M \leq 0.10$	6.340	4.240	2.302	0.478	0.783	3.989
	(0.050)	(0.054)	(0.061)	(0.041)	(0.071)	(0.053)
$0.10 < M \leq 0.20$	8.104	7.321	3.719	4.967	4.367	6.035
	(0.061)	(0.078)	(0.056)	(0.059)	(0.078)	(0.067)
Total	5.123	3.592	2.062	1.767	1.936	3.476
	(0.052)	(0.064)	(0.059)	(0.056)	(0.077)	(0.058)

Table IX: The Influence of Liquidity on Transaction Cost Savings.
This table shows the regression estimates of TCS on liquidity of the market and other determinants. TCS denotes the transaction cost savings of in-the-money options. $Spread$ and DV measures the liquidity difference in bid-ask spreads and trading volume in dollars. The remainings are control variables. Rf is the risk-free rate and DY is dividend yield. Vol is the volatility of S&P 100 Index. The sample period is from 23 July 2001 to 31 December 2010, when the S&P 100 Index options market is relatively liquid. Newey and West (1986) $t-statistics$ are reported in the parentheses. *, ** and *** indicate significance at 10%, 5% and 1% level, respectively.

VARIABLES	TCS					
	(1)	(2)	(3)	(4)	(5)	(6)
$Spread$	-1.743***		-1.653***	-1.817***		-1.743***
	(-3.40)		(-3.20)	(-3.33)		(-3.17)
DV		-1.366	-1.067		-1.623	-1.197
		(-1.15)	(-0.92)		(-1.36)	(-1.02)
Rf				0.006	0.004	0.006
				(1.31)	(0.85)	(1.31)
DY				0.019	0.030*	0.024
				(1.26)	(1.93)	(1.54)
Vol				1.425**	1.759***	1.499***
				(2.57)	(3.02)	(2.64)
Constant	0.319***	0.330***	0.322***	0.233***	0.222***	0.226***
	(54.39)	(51.76)	(51.48)	(6.28)	(5.84)	(6.00)
Observations	1,886	1,887	1,850	1,801	1,806	1,770
Adj R-squared	0.008	0.000	0.007	0.010	0.004	0.009

Table X: Exercise-based Difference.
This table reports the EEP of OEX options indicated by the different exercise style, EBD. The algorithm to calculate both premiums can be seen in Lasser and Spizman (2016). The sample period is from 23 July 2001 to 31 December 2010, when the S&P 100 Index options market is relatively liquid. Newey and West (1986) test results are reported, and * indicates an insignificant difference from 0 at the 5% level.

		Call						Put					
EEP	Group	7–30	30–60	60–120	120–180	180–360	Total	7–30	30–60	60–120	120–180	180–360	Total
EBD	DOTM	0.000	0.000	0.002	0.006	0.016	0.004	0.000	0.000	0.000	0.001	0.001	0.000
	OTM	0.000	0.001	0.007	0.018	0.043	0.006	0.000	0.002	0.001	0.002	0.007	0.002
	ATM	0.001	0.004	0.021	0.047	0.083	0.013	0.006	0.013	0.004	0.006	0.019	0.009
	ITM	0.009	0.014	0.051	0.092	0.153	0.037	0.018	0.043	0.013	0.013	0.037	0.026
	DITM	0.026	0.051	0.128	0.191	0.296	0.123	0.018	0.049	0.014	0.020	0.037	0.028
	Total	0.005	0.007	0.026	0.056	0.112	0.024	0.006	0.012	0.004	0.006	0.017	0.009

Table XI: The NEEP of American Options.
This table reports the percentages of the NEEP of the S&P 100 Index options. After duly accounting for two sources of EEP of American options, we compare the remaining value of XEO and OEX options. Case 1 stands for the EEP that OEX options are more expensive than the otherwise identical XEO options. Case 2 stands for the same value of OEX and XEO options. Case 3 stands for the NEEP that XEO options are more expensive than the otherwise identical OEX options. The averages are reported in parentheses. The sample period is from 23 July 2001 to 31 December 2010, when the S&P 100 Index options market is relatively liquid.

		Call						Put					
Group	Case	7-30	30-60	60-120	120-180	180-360	Total	7-30	30-60	60-120	120-180	180-360	Total
DOTM	1	52.445	69.566	76.441	76.234	77.512	72.259	53.412	62.429	75.426	82.221	79.735	67.316
		(0.020)	(0.022)	(0.030)	(0.034)	(0.037)	(0.029)	(0.014)	(0.017)	(0.027)	(0.035)	(0.036)	(0.023)
	2	4.216	5.829	0.974	0.517	0.585	2.545	15.216	6.757	10.747	6.672	5.636	9.353
		(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)
	3	43.339	24.605	22.585	23.249	21.903	25.195	31.372	30.814	13.827	11.107	14.629	23.332
		(-0.014)	(-0.010)	(-0.009)	(-0.015)	(-0.016)	(-0.012)	(-0.009)	(-0.007)	(-0.010)	(-0.015)	(-0.018)	(-0.009)
OTM	1	65.407	77.300	84.587	85.273	79.691	77.238	67.670	80.191	92.397	95.369	92.549	80.684
		(0.022)	(0.029)	(0.038)	(0.048)	(0.056)	(0.033)	(0.021)	(0.030)	(0.046)	(0.063)	(0.069)	(0.036)
	2	5.510	5.646	1.576	0.751	0.647	3.918	5.449	1.562	2.264	1.505	0.909	2.810
		(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)
	3	29.083	17.054	13.837	13.976	19.662	18.844	26.881	18.247	5.339	3.126	6.542	16.506
		(-0.011)	(-0.011)	(-0.013)	(-0.023)	(-0.028)	(-0.013)	(-0.010)	(-0.009)	(-0.014)	(-0.032)	(-0.024)	(-0.010)
ATM	1	80.119	90.785	89.306	81.984	69.402	85.412	86.165	93.564	98.519	97.842	93.766	92.411
		(0.050)	(0.059)	(0.064)	(0.068)	(0.086)	(0.059)	(0.056)	(0.063)	(0.088)	(0.112)	(0.122)	(0.073)
	2	4.385	2.648	0.565	0.079	0.000	2.510	0.891	0.156	0.255	0.074	0.256	0.417
		(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)
	3	15.496	6.567	10.129	17.937	30.598	12.078	12.944	6.280	1.227	2.083	5.978	7.173
		(-0.019)	(-0.023)	(-0.024)	(-0.043)	(-0.066)	(-0.029)	(-0.018)	(-0.022)	(-0.026)	(-0.042)	(-0.029)	(-0.021)
ITM	1	97.181	98.244	87.611	78.328	65.007	91.679	97.389	95.715	99.469	98.924	96.802	97.323
		(0.116)	(0.115)	(0.104)	(0.101)	(0.112)	(0.112)	(0.149)	(0.137)	(0.184)	(0.196)	(0.190)	(0.159)
	2	0.520	0.540	0.024	0.057	0.000	0.360	0.015	0.000	0.051	0.120	0.457	0.058
		(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)
	3	2.299	1.216	12.365	21.615	34.993	7.961	2.596	4.285	0.481	0.956	2.742	2.619
		(-0.055)	(-0.048)	(-0.048)	(-0.073)	(-0.144)	(-0.090)	(-0.058)	(-0.054)	(-0.057)	(-0.045)	(-0.039)	(-0.054)
DITM	1	97.545	98.741	88.627	81.153	66.690	88.326	98.855	96.493	99.581	98.758	96.681	98.085
		(0.188)	(0.193)	(0.156)	(0.150)	(0.131)	(0.171)	(0.225)	(0.223)	(0.273)	(0.283)	(0.356)	(0.260)
	2	0.055	0.000	0.000	0.000	0.000	0.013	0.000	0.000	0.052	0.000	0.087	0.023
		(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)
	3	2.400	1.259	11.373	18.847	33.310	11.661	1.145	3.507	0.367	1.242	3.231	1.891
		(-0.081)	(-0.07)	(-0.082)	(-0.140)	(-0.232)	(-0.172)	(-0.039)	(-0.071)	(-0.037)	(-0.049)	(-0.077)	(-0.064)
Total	1	81.264	85.455	84.993	80.829	72.182	82.742	76.935	81.044	89.579	93.229	90.392	83.360
		(0.079)	(0.069)	(0.064)	(0.071)	(0.079)	(0.071)	(0.077)	(0.065)	(0.087)	(0.116)	(0.133)	(0.083)
	2	3.161	3.526	0.879	0.360	0.287	2.284	4.733	2.358	4.118	2.261	1.974	3.372
		(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)
	3	15.575	11.019	14.127	18.811	27.531	14.974	18.333	16.598	6.303	4.510	7.634	13.268
		(-0.016)	(-0.014)	(-0.023)	(-0.049)	(-0.109)	(-0.035)	(-0.012)	(-0.011)	(-0.012)	(-0.023)	(-0.025)	(-0.013)

Table XII: Influence of Market Liquidity on the Overvalued Phenomenon of XEO Options.

This table shows the regression estimates of remaining EEP on liquidity of the market and other determinants. $(N)Remain$ denotes the (negative) remaining EEP of the matched options after subtracting the EEP from the Black-Scholes world. $Spread$ and DV measures the liquidity difference in bid-ask spreads and trading volume in dollars. The remainings are control variables. Rf is the risk-free rate and DY is dividend yield, which can affect the early-exercise decision of market participants. Vol is the volatility of S&P 100 Index. The main sample period is from 23 July 2001 to 31 December 2010, when the S&P 100 Index options market is relatively liquid. Newey and West (1986) $t-statistics$ are reported in the parentheses. *, ** and *** indicate significance at 10%, 5% and 1% level, respectively.

VARIABLES	*Remain*						*NRemain*					
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
Spread	-0.036***		-0.035***	-0.034***		-0.033***	-0.000		-0.001	-0.002***		-0.002***
	(-23.38)		(-23.23)	(-23.27)		(-22.99)	(-0.73)		(-1.02)	(-2.90)		(-2.99)
DV		-0.172***	-0.160***		-0.169***	-0.159***		-0.159***	-0.156***		-0.139***	-0.141***
		(-4.00)	(-3.78)		(-3.99)	(-3.81)		(-3.31)	(-3.21)		(-2.79)	(-2.81)
Rf				0.002	0.003	0.002				-0.007***	-0.007***	-0.007***
				(0.84)	(1.40)	(0.94)				(-3.14)	(-3.12)	(-3.10)
DY				-0.006***	-0.007***	-0.006***				0.006***	0.006***	0.006***
				(-2.95)	(-3.00)	(-2.79)				(3.66)	(3.71)	(3.76)
Vol				0.537***	0.531***	0.534***				-0.085	-0.073	-0.054
				(7.87)	(7.80)	(7.78)				(-1.25)	(-1.07)	(-0.78)
Constant	0.072***	0.070***	0.073***	0.062***	0.059***	0.061***	-0.019***	-0.018***	-0.018***	-0.007	-0.008	-0.008
	(1,451.95)	(761.64)	(641.37)	(9.42)	(8.91)	(9.22)	(-360.07)	(-182.21)	(-152.88)	(-0.93)	(-0.96)	(-1.01)
Individual FE	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES
Observations	185,976	186,015	182,200	175,082	175,214	171,616	29,577	29,570	28,963	27,855	27,856	27,297
Adj R-squared	0.006	0.000	0.006	0.020	0.015	0.020	0.000	0.001	0.001	0.008	0.009	0.009

Table XIII: Robustness Tests: Liquidity Differences.
This table shows the liquidity differences between OEX and XEO options in each moneyness-maturity group for calls and puts separately. DOTM, OTM, ATM, ITM, and DITM denote $-0.20 < M \leq -0.10$, $-0.10 < M \leq -0.02$, $-0.02 < M \leq 0.02$, $0.02 < M \leq 0.10$, and $0.10 < M \leq 0.20$. OI and TO measure the liquidity differences in open interest and turnover ratio. Subscripts OEX and XEO stand for OEX and XEO options, respectively. Panel A and B report the proportion and the average value of the OEX option liquidity measure, which are equal or greater than the values of the otherwise identical XEO option. The Newey and West (1986) test results of the average value of the OEX option liquidity measure larger than the matched XEO option liquidity measure are displayed. The sample period is from 23 July 2001 to 31 December 2010, when the S&P 100 Index options market is relatively liquid. * indicates an insignificant difference from 0 at the 5% level.

		Call						Put					
Liquidity	Group	7–30	30–60	60–120	120–180	180–360	Total	7–30	30–60	60–120	120–180	180–360	Total
Panel A: Proportion													
	DOTM	89.376	92.121	96.157	98.106	98.139	94.934	89.728	94.052	96.757	97.803	97.596	94.580
	OTM	89.871	88.340	94.824	97.664	98.009	91.597	89.819	89.459	94.229	97.067	98.228	91.494
	ATM	85.810	89.134	93.896	96.111	96.622	89.797	89.263	90.118	92.525	93.601	96.328	90.873
$TO_{OEX} \geq TO_{XEO}$	ITM	93.671	95.732	97.082	98.749	97.860	95.655	94.674	95.105	96.484	97.071	98.368	95.632
	DITM	97.545	97.850	98.669	99.002	98.946	98.290	96.429	97.150	97.067	98.281	99.214	97.362
	Total	90.500	91.089	95.560	97.903	97.990	93.112	91.065	92.015	95.264	96.895	97.944	93.245
	DOTM	87.268	74.253	72.572	77.038	89.793	77.841	94.150	81.305	70.261	70.545	80.066	79.652
	OTM	90.896	86.478	79.538	81.769	75.261	84.667	92.950	84.416	78.479	84.022	77.783	85.285
$OI_{OEX} \geq OI_{XEO}$	ATM	76.770	81.085	77.436	83.016	72.201	78.593	73.815	76.258	72.668	69.643	68.659	73.916
	ITM	68.103	71.623	72.614	72.753	59.134	69.588	59.033	64.990	62.914	61.626	58.225	61.874
	DITM	59.956	62.821	59.528	70.510	50.457	60.054	47.848	56.247	60.712	62.464	56.594	55.907
	Total	77.394	79.355	75.240	77.714	70.053	76.964	79.640	77.826	71.597	71.678	70.763	75.995
Panel B: Average													
	DOTM	0.082	0.033	0.015	0.011	0.011	0.026	0.042	0.028	0.014	0.009	0.006	0.024
	OTM	0.131	0.045	0.020	0.009	0.009	0.053	0.094	0.040	0.018	0.009	0.009	0.048
	ATM	0.142	0.064	0.025	0.008	0.002	0.075	0.181	0.073	0.025	0.005	-0.004	0.091
$TO_{OEX} - TO_{XEO}$	ITM	0.056	0.031	0.013	0.006	0.001	0.032	0.071	0.038	0.016	0.013	0.005	0.040
	DITM	0.031	0.031	0.007	0.005	0.004	0.018	0.028	0.020	0.009	0.008	0.005	0.016
	Total	0.101	0.044	0.018	0.008	0.006	0.047	0.095	0.041	0.017	0.009	0.005	0.046
	DOTM	1.805	0.662	0.607	1.042	1.240	0.903	1.906	0.783	0.461	0.657	0.702	0.885
	OTM	3.205	1.283	0.838	0.842	0.604	1.525	3.371	1.069	0.859	0.711	0.577	1.650
	ATM	2.217	1.006	0.818	0.682	0.934	1.344	1.450	0.404	0.602	0.315	0.415	0.781
$OI_{OEX} - OI_{XEO}$	ITM	0.260	0.356	0.532	0.490	0.525	0.378	-0.172	-0.227	0.101	0.179	0.033	-0.094
	DITM	0.163	0.284	0.830	1.222	0.402	0.504	-0.134	-0.032	0.146	0.147	0.002	0.008
	Total	1.714	0.894	0.739	0.826	0.735	1.054	1.806	0.628	0.539	0.476	0.414	0.906

Table XIV: Robustness Tests: Influence of Market Liquidity on Early Exercise Premium.

This table shows the regression estimates of the EEP and the remaining EEP on liquidity of the market and other determinants with two new alternative liquidity measures. EEP denotes the EEP of the matched options. *Remain* denotes the remaining EEP of the matched options after subtracting the EEP from the Black-Scholes world. OI and TO measures the liquidity difference in open interest and turnover ratio. The remainings are control variables. Rf is the risk-free rate and DY is dividend yield, which can affect the early-exercise decision of market participants. Vol is the volatility of S&P 100 Index. The sample period is from 23 July 2001 to 31 December 2010, when the S&P 100 Index options market is relatively liquid. Newey and West (1986) $t-statistics$ are reported in the parentheses. *, ** and *** indicate significance at 10%, 5% and 1% level, respectively.

VARIABLES	EEP						*Remain*					
	(1)	(2)	(3)	(4)	(5)	(6)	(1)	(2)	(3)	(4)	(5)	(6)
OI	-0.006***		-0.006***	-0.006***		-0.006***	-0.005***		-0.005***	-0.005***		-0.005***
	(-20.33)		(-19.63)	(-20.27)		(-19.52)	(-19.50)		(-18.89)	(-19.28)		(-18.65)
TO		-0.036***	-0.027***		-0.035***	-0.027***		-0.027***	-0.021***		-0.026***	-0.020***
		(-18.13)	(-14.42)		(-18.41)	(-14.52)		(-15.21)	(-12.09)		(-15.34)	(-12.12)
Rf				-0.001	0.000	-0.002				0.001	0.002	0.001
				(-0.57)	(0.02)	(-0.77)				(0.47)	(1.04)	(0.30)
DY				-0.009***	-0.010***	-0.009***				-0.006***	-0.007***	-0.006***
				(-3.39)	(-3.72)	(-3.37)				(-2.82)	(-3.04)	(-2.73)
Vol				0.517***	0.532***	0.518***				0.524***	0.537***	0.526***
				(6.46)	(6.51)	(6.41)				(7.83)	(7.85)	(7.76)
Constant	0.085***	0.081***	0.086***	0.085***	0.080***	0.086***	0.075***	0.071***	0.076***	0.065***	0.061***	0.066***
	(333.09)	(909.55)	(320.48)	(11.38)	(10.48)	(11.56)	(359.78)	(884.14)	(339.52)	(10.09)	(9.27)	(10.17)
Individual FE	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES
Observations	198,967	198,961	194,972	187,298	187,295	183,586	185,977	185,995	182,242	175,128	175,141	171,649
Adj R-squared	0.026	0.006	0.029	0.040	0.020	0.043	0.019	0.004	0.022	0.033	0.019	0.036

Table XV: Robustness Tests across Moneyness and Maturity Groups.
This table shows the robustness tests of negative remaining EEP ($NRemain$) on liquidity of the market and other determinants across moneyness and maturit y groups. DOTM, OTM, ATM, ITM, and DITM denote $-0.20 < M \leq -0.10$, $-0.10 < M \leq -0.02$, $-0.02 < M \leq 0.02$, $0.02 < M \leq 0.10$, and $0.10 < M \leq 0.20$. $NRemain$ denotes the negative remaining EEP of the matched options after subtracting the EEP from the Black-Scholes world. $Spread$ and DV measures the liquidity difference in bid-ask spreads and trading volume in dollars. The remainings are control variables. Rf is the risk-free rate and DY is dividend yield. Vol is the volatility of S&P 100 Index. The main sample period is from 23 July 2001 to 31 December 2010, when the S&P 100 Index options market is relatively liquid. Newey and West (1986) $t-statistics$ are reported in the parentheses. *, ** and *** indicate significance at 10%, 5% and 1% level, respectively.

Variables	Moneyness					Time to Maturity				
	DOTM	OTM	ATM	ITM	DITM	7–30	30–60	60–120	120–180	180–360
$Spread$	-0.004***	-0.001	0.007	0.034	-0.027	0.001	-0.004***	-0.015***	-0.014**	-0.036**
	(-5.44)	(-1.02)	(1.28)	(0.30)	(-0.05)	(1.61)	(-5.08)	(-4.92)	(-2.41)	(-2.28)
DV	-0.540**	-0.238***	0.054	1.217***	2.773***	-0.185***	-0.198*	0.433*	-0.552	0.640
	(-2.49)	(-3.75)	(0.81)	(2.78)	(2.87)	(-3.74)	(-1.89)	(1.77)	(-0.72)	(0.92)
Rf	-0.005***	-0.003***	0.008	0.011	-0.028	-0.008**	-0.002	-0.005***	-0.005	-0.003
	(-5.31)	(-2.69)	(1.23)	(1.04)	(-1.66)	(-2.52)	(-0.93)	(-2.58)	(-0.78)	(-0.40)
DY	0.003**	0.004**	-0.002	0.053	-0.008	-0.003	-0.000	-0.004	0.027**	0.010**
	(2.24)	(2.19)	(-0.28)	(1.41)	(-0.13)	(-1.16)	(-0.08)	(-1.23)	(2.25)	(2.47)
Vol	-0.271***	-0.213***	0.585	2.188***	2.430**	-0.185**	0.114	-0.480***	0.762*	1.117**
	(-6.01)	(-3.35)	(1.36)	(3.66)	(2.58)	(-2.39)	(1.24)	(-3.80)	(1.90)	(2.34)
Constant	0.006	-0.002	-0.064*	-0.260***	-0.074	0.018**	-0.007	0.018*	-0.098***	-0.094***
	(1.34)	(-0.32)	(-1.67)	(-2.87)	(-0.59)	(2.02)	(-0.91)	(1.82)	(-2.70)	(-2.66)
Individual FE	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES
Observations	8,997	12,175	3,510	1,904	711	8,351	9,995	4,546	1,807	2,598
Adj R-squared	0.038	0.013	0.011	0.076	0.082	0.016	0.005	0.027	0.016	0.019

Table A.1: Literature on Pricing American Options.
This table shows the literature on pricing American options published on top three journals. The literature is listed in the first column. The second column is the type of the dividends considered in the literature. The last column is the model the literature employed.

Literature	Dividend	Model
Brennan and Schwartz (JF, 1977)	Discrete	BS Lognormal Distribution
Schwartz (JFE, 1977)	Discrete	BS Lognormal Distribution
Roll(JFE, 1977)	Discrete	BS Lognormal Distribution
Geske(JFE, 1979)	Discrete	BS Lognormal Distribution
Cox, Ross, and Rubinstein (JFE,1979)	Continuous	The Binomial Tree
Whaley(JFE, 1981)	Discrete	BS Lognormal Distribution
Whaley(JFE, 1982)	Discrete	BS Lognormal Distribution
Geske and Johnson(JF, 1984)	Discrete	BS Lognormal Distribution
Geske and Roll (JF, 1984)	Discrete	BS Lognormal Distribution
Barone-Adesi and Whaley (JFE, 1986)	Discrete	BS Lognormal Distribution
Whaley(JF, 1986)	None	BS Lognormal Distribution
Barone-Adesi and Whaley (JF, 1987)	Continuous	BS Lognormal Distribution
Nelson and Ramaswamy(RFS, 1990)	Continuous	CEV
Kim(RFS, 1990)	Continuous	BS Lognormal Distribution
Bunch and Johnson(JF, 1992)	None	BS Lognormal Distribution
Rubinstein(JF, 1994)	None	The Binomial Tree
Amin and Bodurtha Jr(RFS,1995)	None	The Binomial Tree
Broadie and Detemple(RFS, 1995)	Continuous	BS Lognormal Distribution
Bates(RFS, 1996)	Continuous	Geometric Jump Diffusion with Stochastic Volatility
Broadie and Detemple(RFS, 1996)	Continuous	BS Lognormal Distribution
Huang, Subrahmanyam, and Yu(RFS, 1996)	None	BS Lognormal Distribution
Carr(RFS, 1998)	Continuous	Merton Jump Diffusion Model
Ju(RFS, 1998	Continuous	BS Lognormal Distribution
Ritchken and Trevor(JF, 1999)	None	GARCH with Stochastic Volatility Processes
Sullivan(RFS, 2000)	None	Quadrature
Buch and Johnson (JF, 2000)	None	BS Lognormal Distribution
Longstaff and Schwartz (RFS, 2001)	Continuous	BS Lognormal Distribution and Merton Jump Diffusion Model
Andricopoulos, Widdicks, Duck, and Newton(JFE, 2003)	Discrete	Quadrature
Broadie, Chernov, and Johannes(JF, 2007)	None	DPS Affine Jump Diffusion
Andricopoulos, Widdicks, Newton, and Duck(JFE, 2007)	Both	Quadrature
Medvedev and Scaillet(JFE, 2010)	Continuous	Stochastic Volatility and Stochastic Interest Rates with BS PDE
Chen, Harkonen, and Newton(JFE,2014)	Both	Quadrature

Figures

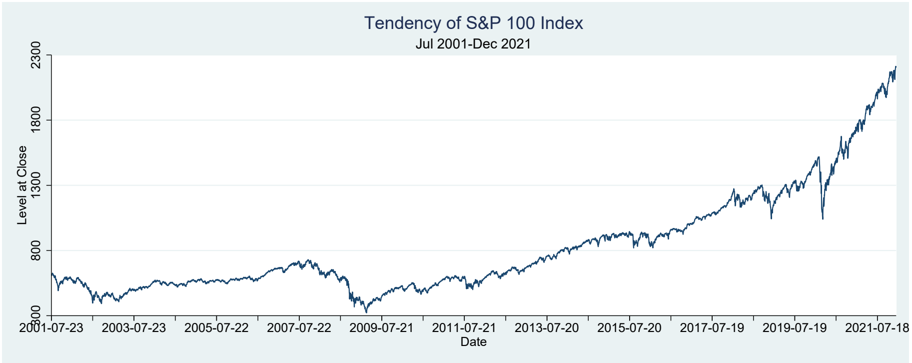

Figure 1: Tendency of S&P 100 Index.
This figure shows an upward tendency of S&P 100 Index from 23 July 2001 to 31 December 2021. It ranges from the minimum with 322.13 on 9 March, 2009 to 2,194.58 at the end of the sample period.

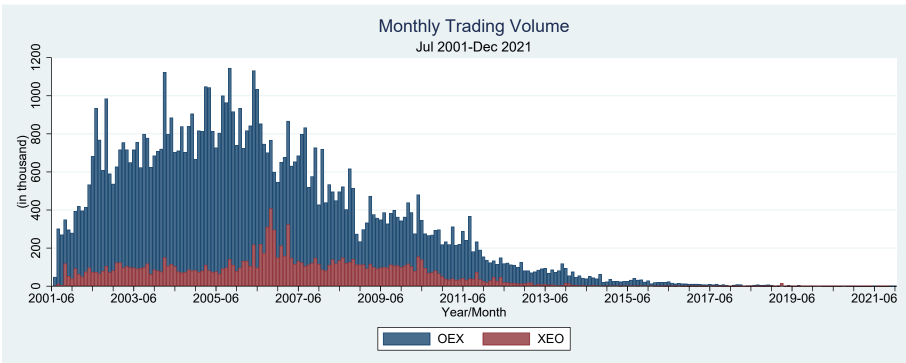

Figure 2: Monthly Trading Volume of OEX and XEO Options.
This figure shows the tendency of monthly trading volume of OEX and XEO options from 23 July 2001 to 31 December 2021. The blue bar stands for the monthly trading volume of OEX options, and the red bar stands for the monthly trading volume of XEO options.