Affirming Market Efficiency of the Athens Derivatives Exchange via Traditional Static Arbitrage Tests

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Abstract

Pricing and trading practices in the Athens Derivatives Exchange, a newly established derivatives market, result in profit opportunities for a selective group of market participants. We investigate the validity of the put-call parity and box spreads in the presence of various forms of market frictions. We infer that profitable arbitrage opportunities are potentially open only to market makers who comprise the most privileged class of market participants and bear the lowest levels of transaction costs.

1. INTRODUCTION

The essence of this study is to examine the existence of arbitrage opportunities prevailing in the Athens Derivatives Exchange (ADEX). The Greek derivatives market is new and is scarcely investigated; to our knowledge, this is the first study that involves an empirical analysis of the ADEX efficiency by investigating the FTSE/ASE-20 Index options. Market efficiency is pondered by examining the validity of the put-call parity and of the box spread strategy. These are traditional static tests and are employed to account for various types of market frictions.

The study's results lead to the conclusion that the FTSE/ASE-20 Index options offered various forms of arbitrage opportunities to low cost traders since their debut in the Greek financial market. Unlike other emerging derivatives markets, ADEX presents financial characteristics found in mature and highly developed derivatives exchanges like the CBOE and LIFFE. For instance, put options are relative overpriced compared to the counterpart call options.

The put-call parity relation is tested via the creation of two zero payoffs portfolios with positions in the index and in call and put options. The analysis includes various levels of transaction costs that best represent the three different classes of ADEX participants. It is found that a form of ADEX inefficiency could have allowed market makers to exploit considerable arbitrage opportunities, mainly because they face significant low transaction fees. On the contrary, substantial arbitrage opportunities were less frequent for proprietary traders and non-existent for individual traders.

The box spread parity test revealed that substantial and economically meaningful arbitrage opportunities were present during the early trading history of ADEX. At a later stage, the market became strongly resilient and operating similarly to developed and matured markets. This is expected since in contrast to the put-call parity test, box spread arbitrage does not include the creation of a proxy portfolio for trading the index and is also inexpensive.

The specific derivatives exchange under review can be considered as an emerging market. The study's results contribute in certain ways to comprehend the efficiency evolution for this nascent market. This is a prominent event since it is intriguing to examine how fast the market participants can learn to rationalize their derivatives pricing activity. All three tests employed, show that the market was inefficient during its early trading history.

Furthermore, it is found that the aftermath of the terrorist attacks in the twin towers has signaled a new era for ADEX efficiency; whereas before the 9/11 attacks the put-call parity was violated due to call overpricing, the violations are reversed after this shocking event. The latter is in the same line of thought with the fundamental parity violations "cycles" initially suggested by Evnine and Rudd (1985). There is also the striking fact that the puts overpricing is systematic and grows in magnitude during the last few months of the available sample creating in this sense profitable arbitrage opportunities for the low cost traders.

2. THE OPTIONS AND FUTURES MARKET FOR THE FTSE/ASE-20

The Athens Derivatives Exchange and the Athens Derivatives Exchange Clearing House (ADECH) commenced their operations in August 1999. The first traded futures and European type index option contract on FTSE/ASE-20 started trading in late August 1999 and early September 2000 respectively. FTSE/ASE-20 is a blue chip index comprised of the twenty largest stocks traded on the Athens Stock Exchange (ASE). FTSE/ASE-20 was chosen as the first underlying instrument for the options and futures contracts because is an index with international recognition that offers adequate liquidity and market depth.

The FTSE/ASE-20 futures and option contracts are quoted in terms of index points, are settled in cash and the settlement amount is found by using the contract multiplier which is equal to 5 euros. Futures and option contracts mature at the close of trading on the third Friday of their expiration month. There are futures and option contracts with six different expiration months; there are contracts that mature in each of the upcoming three months (the closest months to the current expiration) and contracts that mature in the March, June, September and December cycle as long as they are not included in the earlier expiration category. In the case of option contracts, for each new expiration month, there are eleven different exercise prices symmetrically distributed around the level of the index.

At present, there are nine members of ADEX that operate as market markets for futures and option contracts that also (might) hold a seat at the ASE. These dealers are either large institutional banks or financial subsidiaries that also belong to a bank consortium and are obliged to adhere to many trading and statutory rules. Their most important responsibility is to enhance the market liquidity by constantly providing bid and offer quotes for the two closest to expiration series of contracts for both futures and options. Moreover, in the case of options, they are obliged to quote values for three exercise prices: at-the money contracts, one above and one below the current index level. For the other exercise prices of the two-upcoming expiration months their obligation is not continuous. In order to safeguard a satisfactory level of liquidity, ADEX officers allow market makers to trade at notably low levels of transaction costs in both futures and options; this trading privilege in conjunction with the fully automated electronic trading system that shrinks the price spreads, enables them to take advantage of any arbitrage opportunities quite easier than any other trader[1].

Proprietary traders are the second category of ADEX participants. They place own orders as well as on behalf of their clients, and have limited obligations compared to market makers; consequently they face higher transaction costs. Finally, member-agents/brokers comprise the third category of ADEX participants. They are not allowed to conduct own transactions however they can introduce orders on behalf of their clients into the trading system.

This study is reviewing the ADEX market efficiency from the perspective of a market maker and an occasional individual trader. Results about the proprietary traders are also listed but are not discussed in detail[2]. Table 1 illustrates our assumptions regarding the fixed and variable transaction costs for trades on the FTSE/ASE-20 Index and the related futures and option contracts.

3. DATA EMPLOYED, AND METHODOLOGICAL ISSUES

3.1 The data

We have available all quoted call (hereafter *c*) and put (hereafter *p*) European type options for the FTSE/ASE-20 Index during the period January 2001 to

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[1] If an arbitrage opportunity exists in the market, then the market makers have a distinct competitive advantage of turning it into a profitable trade over other kind of traders (Evnine and Rudd, 1985). Furthermore, market makers are the only ones that can act as pure arbitrageurs since according to interviews conducted by Blomeyer and Boyd (1995) among floor traders: "a good arbitrage trader knows tick-for tick what arbitrage opportunities exist at any point, and that they act upon them very quickly".

[2] Proprietary traders act many times as market makers and bear similar transaction costs with them in cases that they are asked by the ADEX officers. Due to this peculiarity, they can be considered as a special case of market makers.

March 2003. The data was obtained from the research department of ADEX. These options are satisfactorily liquid for series contracts maturing in the upcoming two months whilst for longer maturities their trading is relative thin.

In order to create an informative options dataset, the following filtering rules are adopted; these are in accordance with the ADEX algorithm used to calculate the options closing prices. Firstly, all transactions with zero entry values in the open–high–low and close price fields are eliminated. Apparently, these refer to transactions that were listed in the ADEX trading system but never quoted or traded[3] by any market participant. Also, a similar category of option observations with zero value entries for the open–high and low price fields but a non-zero closing price is excluded. These represent non-zero open interest - zero volume contract transactions. Finally, and in the spirit of Bakshi et al. (1997), option transactions with closing prices less than 1 index point are also excluded from the dataset; such option prices are presumed insignificant and might be dominated by speculative trading.

The original dataset includes more than 145,000 datapoints, but following the thorough filtering process the resulting dataset has 13,298 datapoints that correspond to 30 different expiration dates. After weeding out more than 90% of the raw observations, it is almost certain that the final dataset includes options that present liquidity during a trading day. From these, 6,024 are call options and the remaining 7,274 refer to put options. Each closing option price is matched with the closing FTSE/ASE-20 Index value, symbolized with S. Moreover, time to maturity, symbolized with T, for

[3] These refer mostly to long maturity options as well as options that are deep in and deep out of the money. In fact, they refer to transactions that exhibit zero open interest and zero volume during a trading day.

each option transaction is calculated according to calendar days. EURIBOR rates (symbolized with *r*) are used as a proxy for the risk-free rates. For options with one, two or three month(s) to expire, the corresponding one, two and three month(s) EURIBOR rate is being used, whilst for longer maturity options the twelve months' rate is considered. Since large players and market makers are closely involved with a commercial bank, EURIBOR rates can be perceived as the prevailing borrowing and lending rates. This complies with the fact that there is no risk-involved in the arbitrage parities employed in this study, hence borrowing or lending should be done with the risk-free rate (Klemkosky and Resnick, 1979). Furthermore, it is considered that a continuous dividend yield, symbolized with δ, is paid by the underlying asset. In this case, δ is taken to be fixed and equal to 2% for options trading during April to August of each year[4].

3.2 Methodological issues for testing the arbitrage relations

Various methodological issues related with arbitrage conditions employed in this study, and especially related to the put-call parity (pcp), are considered below. In accordance with previous literature (Evnine and Rudd, 1985, Kamara and Miller, 1995, Gay and Jung, 1999, Cavallo and Mammola, 2000, Ackert and Tian, 2001), the put-call parity (pcp) testing is based on index replication for a number of reasons. Firstly, the FTSE/ASE-20 can be easily and inexpensively replicated by a proxy portfolio of 8 to 10 liquid stocks. Former studies, for instance, by Evnine and Rudd (1985) and Kamara and Miller (1995), assume replication of wide-coverage indices like the S&P 100 or S&P 500. Index replication in the case of FTSE/ASE-20 that

[4] It is known that the companies comprising the index paid out dividends from April to August of each year with no noticeable cluster of dividend payments occurring at any particular period. Therefore, it is assumed that holding the dividend yield constant would not affect the calculation of the arbitrage relations as well as the futures.

includes only 20 stocks is manageable, more efficient and feasible even via the Stock Reverse Repo agreements that are traded in the ADEX. Withal, tracking error can be minimal (Evnine and Rudd, 1985) and even favourable during adverse market moves under subtle active management of the proxy portfolio. Secondly, it is not wise to use the futures contracts since their liquidity is thin for maturities exceeding two months; about 40% of the call and put options have 30-60 days to maturity and another 20% more than 60 days to maturity. So, the choice of the liquid one month futures contract would not secure the arbitrage profits due to the resulting basis risk[5]. Thirdly, the pcp via index replication is a conservative test of market efficiency since the transaction costs associated with this are by far larger compared with the use of the futures on the index. Additionally, short selling the index becomes practically feasible by assuming a quasi-arbitrage (i.e., Kamara and Miller, 1995, Gay and Jung, 1999, Cavallo and Mammola, 2000). Of course, only market makers could systematically engage without cost in a quasi-arbitrage trading, since they continually manage large portfolios and are favoured by market frictions.

In the period we examined there are no intraday prices available by the ADEX research department, so like the study of Ackert and Tian (2001), closing prices, which are non-synchronous, constitute the best alternative solution. But this should not raise any objections about the market efficiency tests of this study since Evnine and Rudd (1985) conjecture that closing option prices are appropriate for analysis because they are representative of the transaction prices that prevail during a trading day. Furthermore, Kamara and Miller (1995) have affirmed similar results about the pcp validity with intraday and closing option prices. Furthermore,

[5] In addition, possible futures mispricing could introduce bias in the pcp tests in favour of the market efficiency hypothesis.

according to Finucane (1991), studies that employ intraday index might still suffer from the non-synchronous of the prices since component stocks do not trade simultaneously and the index level at any point will reflect some stale quotes. Based on the aforementioned facts, we make the assumption that if arbitrage opportunities exist for closing prices, then it should also be present during trading sessions where the ADEX and ASE are operating simultaneously.

The available data does not include bid-ask quotes. Similarly to Mittnik and Rieken (2000), the bid-ask spread is ignored and closing prices are assumed to be the transaction prices for the call and put options. According to Ackert and Tian (2001), the use of the bid-ask prices rather than closing is conservative in testing the pcp relationship and biased in favour of the market efficiency hypothesis since it implies an additional source of transaction (see also Phillips and Smith, 1980). Nevertheless, studies like the one of Bakshi et al. (1997)[6], Dumas et al. (1998) and Bates (2000) that examine options prices in a different context, use the bid-ask midpoint prices since, in most cases, the trading of these contracts is realized somewhere inside the spread[7].

Based on previous studies' definitions (Black and Scholes, 1972, Galai, 1977, Mittnik and Rieken, 2000), a market is considered to be efficient, with respect to given information set, if no trader can consistently take advantage of arbitrage opportunities that lead to risk-adjusted profits above the prevailing risk-free rate after the deduction of transaction costs.

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[6] Bakshi et al. (1997) report that their results based on options transaction prices are similar to those based on bid-ask quotes midpoint.

[7] Unlike some of the oldest and largest derivatives exchanges that heretofore rely on the open outcry trading system, ADEX trading is done with an advanced electronic system that secures greater execution efficiency, transaction transparency and narrower bid-ask spreads.

Due to the nature of the available data, it is assumed that the statistical relation of an arbitrage condition, like the pcp, corresponds to the economic significance of the parity violations. The statistical significance of an arbitrage relation points towards the fact that violations exist if the prevailing closing prices fail to satisfy the fundamental parity under consideration (i.e., Hemler and Miller, 1991). The economic significance of the parity violations refers to the possibility of the arbitrage profit realization via actual trading on the prevailing quotes. This is usually validated with ex-ante tests (i.e., Galai, 1977) where the arbitrage position triggered by the pcp violation is executed with a time delay, usually of few minutes. The nature of the available data does not allow the simulation of a timely test since the potential ex-ante test with one-day lag is too long to be realistic and does not preclude the introduction of premiums implied by the immediacy risk (i.e., Kamara and Miller, 1995).

4. EMPIRICAL PERFORMANCE OF THE PUT-CALL PARITY

The put-call-parity relation (i.e., Stoll, 1969) for European options that are written on an index that pays a continuous dividend yield is described by the following equation (i.e., Hull, 2003):

$$c + Xe^{-rT} - p - Se^{-\delta T} = 0 \qquad (1)$$

This relation is valid for European style options as in the case of FTSE/ASE-20 Index options, and always holds in the absence of arbitrage opportunities; otherwise, by transacting on options and the underlying index a trader might be able to reap arbitrage profits. Call and put options that are validated with the pcp should have the same exercise price, X, and time to maturity, T. The pcp has been used widely as a weak market efficiency test by many authors (see Kamara and Miller, 1995, Mittnik and Rieken, 2000, Cavallo and Mammola, 2000, Ackert and Tian, 2001). It is an appealing formula for testing market efficiency, since it does not depend on the use of any theoretical option pricing model and does not imply any distributional assumptions about the evolution of the underlying index level and the agent's risk preferences in time.

We create 3,050 put-call parity pairs out of the 6,024/7,274 available call/put observations. Moreover, we also exclude all options with maturity less than seven calendar days (see Cavallo and Mammola, 2000) reducing thereby the matched pcp-pairs to 2,875.

The extended formulas for various forms of market frictions are as follows (see Cavallo and Mammola, 2000):

$$c - p - Se^{-\delta T} + Xe^{-rT} \leq (k_{OS} + k_{OL} + k_X)/M + (e^{-rT}k_{SS} + k_{SL})S \qquad (2)$$

$$p - c + Se^{-\delta T} - Xe^{-rT} \leq (k_{OS} + k_{OL} + k_X)/M + (k_{SS} + e^{-rT}k_{SL})S \qquad (3)$$

with k_{SS}/k_{SL} to be the cost of selling/buying the index, k_{OS}/k_{OL} to represent the cost of selling/buying an option, k_X to be the exercise fee and M to represent the options index multiplier that is needed in order to convert the euro cost into index units. Transaction costs that are realized at the expiration of the options are discounted with r. Equation (2) is the case of the long pcp hedge (conversion) which as part of the arbitrage strategy includes the short position on an overvalued call option and the long position on a synthetic call option created by the index and the put contract. Eq. (3) refers to the short pcp hedge case (reversal). When violated, pcp leads to the realization of an instance cash inflow with a zero cash outflow at the options expiration date.

The existence of arbitrage opportunities is checked by simulating the outcome of the Eqs. (2) and (3) with the transaction costs shown in Table 1. We consider that the transaction costs used in the analysis are representative or even slightly above the actual commissions paid for the period under investigation (and relatively higher compared with some previous studies[8]). The results obtained from this test are tabulated in Table 2. Six different scenarios are exhibited, each for a different level of transaction cost. The maximum number of arbitrage opportunities is observed under the no transaction costs case (Cost=Zero). As transaction costs increase according to the type of market trader, the percentage of profitable arbitrage opportunities decreases. For example, in the case of transaction costs incurred by market makers (Cost=MM), only 11% (40%) long (short) arbitrage of all trades represent profitable opportunities. The mean values of these long (short) opportunities are equal to 12.69 (8.51) index points whilst the median values are slightly smaller and equal to 10.18 (7.11) index points. Given the fact that long or short pcp arbitrage positions have skewed distributions (Mittnik and Rieken, 2000) an upper-tailed (two-tailed) null hypothesis test of a zero population mean (median) is also reported in Table 2 by using the Chen's (1995) modified *t*-statistics (a nonparametric signed rank test)[9]. From these statistics it is obvious that arbitrage profits of either position for market makers are strongly significant

[8] On average, market makers pay 5.22 index points (26.1 euros) for replicating the index and 0.3 euros (0.06 index points) to trade any option contract, whilst individual traders pay 22.19 index points (110.95 euros) and 10 euros (2 index points) respectively. Cavallo and Mammola (2000) assume 5 and 10 index points for index replication for the arbitrageurs and the individual inventors whilst 1 and 1.5 index points for options trading respectively. Mittnik and Rieken (2000) assume for market makers, on average, 10 euros for index replication and 0.20 euros for options trading. Finally, Kamara and Miller (1995) assume, on average, that commissions and bid-ask spreads yield transactions costs of 0.38% of the S&P 500 cash index value in contrast with 0.4% that is assumed in this study for market makers (only for index replication).

[9] The upper-tailed Chen's *t*-test is employed for testing: $\boldsymbol{H_0}$: $\mu=0$ *vs* $\boldsymbol{H_0}$: $\mu>0$ and under the null, the modified *t*-test has a Student-*t* distribution with n-1 degrees of freedom (where n is the sample size). The two-tailed sign test, z, is employed for testing: $\boldsymbol{H_0}$: $\mu=0$ *vs* $\boldsymbol{H_0}$: $\mu\neq0$ and under the null z follows the standard normal distribution.

at the 1% level. In the case of an individual trader, (Cost=Ind), such arbitrage opportunities do not exist, practically. The values of the Chen's *t*-test and the nonparametric *z*-value are mainly reported to gauge the relative persistence of the arbitrage profits for market participants compared with the counterpart zero-transaction cost case[10].

The above results are in line with studies conducted for other markets like the ones of Klemkosky and Resnick (1980) for the Chicago Board of Exchange, Nisbet (1992) for the London Traded Option Market and Mittnik and Rieken (2002) for the German Options and Futures Exchange. According to these studies, short arbitrage opportunities are much more frequent than long ones even after the inclusion of transaction costs. Furthermore, when large transaction costs have to be incurred to fully exploit an arbitrage opportunity (like the case of individual traders), pcp eventually fails to indicate market inefficiency (Cavallo and Mammola, 2000, Ackert and Tian, 2001). In the context of the study's results though, pcp reveals the existence of several potential arbitrage opportunities, at least for the case of market makers that face relatively low transaction costs.

In the market makers case – even for the proprietary traders - the pcp results shown in Table 2 indicate that the option market is not efficient and considerable arbitrage opportunities could have been realized. Regarding the individual traders, there is confirmatory evidence to support the market efficiency hypothesis. To cast as much doubt as possible about the arbitrage results prevailed in the case of market makers, the pcp investigation is bolstered by repeating the simulation of Eqs. (2) and (3) for three additional cases: *i)* Cost=MM(A): replication of the index is done via Stock Reverse Repo by assuming that index short sales proceedings are multiplied by factor $\gamma=1-$

[10] It is more meaningful to compare the arbitrage profits of the market participants by using the *t*-test or *z*-test rather than using only the mean value of the violation.

1.5rT, γ<1, with transaction costs as in Cost=MM, *ii)* Cost=MM(B): market makers incur different transaction costs for buying/selling the index that are equal to 0.6% (150% larger than the real ones), and *iii)* Cost=MM(C): market makers bear 0.6% transaction costs for index replication and net index short sales proceedings account for the γ factor (combined MM(A) and MM(B) cases). Case *i)* reflects the opportunity cost of having 150% of the proceeds in a margin account earning no interest (Ackert and Tian, 2001) and applies in the case of ADEX, case *ii)* is considered as makeweight of the fact that we do not use bid-ask prices, whilst case *iii)* is an extreme scenario that overstates all kind of transaction costs.

These cases are illustrated in the last three columns of Table 2. It is evident that in either case, market makers still have the greatest opportunity to earn arbitrage profits. Even in the most extreme case, there are in total 700 economically and statistically significant violations. Nevertheless, in the case where index replication for short selling reasons is difficult and expensive these results are in line with those of Kamara and Miller (1995) and demonstrate that beyond the profitable conversion, there were substantial quasi-arbitrage opportunities. In accordance with Gould and Galai (1974), Klemkosky and Rsnick (1979), Envine and Rudd (1985), the overall results suggest that pcp arbitrage opportunities are potentially open only for market makers who bear low transaction costs.

To investigate pcp violations further, Table 3 tabulates a monthly analysis of the long and short pcp profitable hedges under zero transaction costs and market frictions faced by market makers as in MM(A) case. In addition to validating the statistical market efficiency of ADEX, Table 4 exhibits the results obtained after estimating the following regression equation:

$$(c-p)/S = \beta_1 + \beta_2((Se^{-\delta T} - Xe^{-rT})/S) + \varepsilon \quad (4)$$

This equation is a rearranging of the pcp (Stoll, 1969) and as in Klemkosky and Resnick (1979), all variables are scaled by the index level. This helps to eliminate heteroskedasticity effects that might otherwise arise from serial correlation in the residuals of options of comparable moneyness and maturity (Bates, 2000). Under market efficiency, β_1 and β_2 should be statistically equal to zero and unity respectively. A statistical positive (negative) intercept indicates overvalued calls (puts) relative to the counterpart put (call) options. The linear regression equation is estimated for the whole sample as well as for four consecutive sub-periods.

The following inferences can be conjectured by the results shown in Tables 3 and 4. Firstly, it is obvious that during the first year of options trading (until August, 2001) and under the zero transaction costs case, there were more long profitable hedges than short ones; in conjunction with the regression estimates for the sub-period January to June of 2001, it can be inferred that the pcp long hedge violations are caused by overpriced call options premiums. The reverse is true for all subsequent months. It is evident that after October 2001, the pcp violations trend is reversed since put options become relative overpriced compared with call options. There is striking evidence from Tables 3 and 4 that short hedges were strengthened unfavorably against the market efficiency after October 2001. Judging from the pooled regression results for the whole period, the intercept is loaded with a statistically significant negative value indicating that the at-the money call options were on average underpriced relatively to the at-the money puts. The study's results affirm the Evnine and Rudd (1985) conjecture about "cycles" of over- and undervaluation of options and in a way preclude the possibility of observing profitable arbitrage opportunities due to the nonsynchronous index and options prices.

Secondly, the results in the cases of market makers with short sales proceeding restrictions, MM(A), are in line with the aforementioned case. Profitable conversions were opened and were more prominent compared with reversals until August 2001 only. Thereafter, it is true that the options market exhibits efficiency with respect to the long hedges but this is achieved at expense of noteworthy short hedge inefficiency; in fact, in the latest months of the sample, market makers could have been benefited from economically significant short arbitrage opportunities. Only during the period from January to March 2001, the options market had been arbitrage – free. It seems that this was a transition period that served as a buffering gap and contributed to the reversal of the long profitable hedges to short ones[11].

Thirdly, the fact that only profitable reversals are possible for market makers after the October 2001 is very intriguing. This might be considered as an aftermath shock caused by the terrorist attacks of September 11, 2001. After this globally shocking event, profitable long hedges ceased to exist because market participants were willing to pay additional and abnormal premiums to take a position in a put contract. The former can be asserted from the intercept coefficient sign and size of the sub-period regressions shown in Table 4; the consecutive reinforcement of the sub-periods regressions intercept to smaller negative values, testimonies that the put options overpricing tendency becomes stronger as time passes.

[11] In fact, the profitable hedges reversal from long to short is evident from the at-the-money implied volatility spread of call options over put options. Whereas during 2001 there is a strong positive spread, the reverse is true for the rest months included in the analysis and quite larger for the latter months of the sample. It is also prominent that the reversal took place during January to March of 2002, a time interval that the spread had shrank.

Finally, the pcp violation results obtained for the ADEX options converges with previous literatures remarks. As with Gould and Galai (1974), Klemkosky and Resnick (1980) and Mittnik and Rieken (2000), profitable conversions (overvalued calls) occurred in the early history of options trading whereas in the latter time, profitable reversals (overvalued puts) constitute the pcp violations stimulus (Kamara and Miller, 1995, Mittnik and Rieken, 2000, Cavallo and Mammola, 2000, Ackert and Tian, 2001). Of course, the timing and magnitude of profitable reversals in the case of ADEX might be interrelated with the boosting of worldwide market uncertainty incepted after the black September of 2001.

All in all, the results have shown that there were substantial and economically significant long pcp arbitrage opportunities during the early trading history of the ADEX; this disputes the market efficiency of ADEX for this early period but it is consistent with international evidence that documents pcp violations for newly established derivatives exchanges. After August 2001 and based on the pcp test, the market should be considered efficient from the perspective of an individual trader. For market makers, the pcp revealed that the market has never been efficient except from the first three months of 2002. Even if no market participant could have exploited the profitable reversals due to the difficulty of short selling the index, still the fundamental pcp relation is severely violated implying irrational price quoting.

Consequently, market makers were able to secure arbitrage-profits if they were able to exploit the short arbitrage strategy of Eq. (3). According to Mittnik and Rieken (2000), agents are expected to gradually learn how to price new derivatives products so that violations of rational option pricing would decrease over time. This reasoning is highly untrue for options traded in the ADEX and from the market makers point of view and contrary to international evidence (Blomeyer and Boyd, 1995), arbitrage profits do not decrease as the market matures.

To pursue the derivative market efficiency further, we continue our analysis by examining box spread arbitrage opportunities as well.

5. BOX SPREAD MISPRICING RATES

The box spread strategy involves the trading of synthetic futures contracts with two pairs of European type put and call options that have different exercise prices but a common expiration date. Let X_H and X_L denote two different exercise prices with $X_H>X_L$. Additionally, let c_H (p_H) to be the value of a call (put) option with the high exercise price and c_L (p_L) to be the value of a call (put) option with the low exercise price. A contemporaneous long and short (short and long) position to a call and a put option with exercise price equal to X_L creates a synthetic long (short) futures contract priced at X_L.

Specifically, the long (short) box spread involves the purchasing (selling) of a synthetic futures priced at X_L and the selling (purchase) of a synthetic futures priced at X_H. Under the no-arbitrage assumption and some levels of transaction costs, the long or short box spread should satisfy the following relations per se (other notation is as before):

$$(c_H - p_H) - (c_L - p_L) + (X_H - X_L)e^{-rT} \leq 2(k_{OS} + k_{OL} + k_x) \qquad (5)$$

$$(c_L - p_L) - (c_H - p_H) + (X_L - X_H)e^{-rT} \leq 2(k_{OS} + k_{OL} + k_x) \qquad (6)$$

Thus a long box spread strategy shown in Eq. (5) resembles a risk-less investment since at the end of the expiration date it ensures a certain inflow of $X_H - X_L$. The short box spread shown in Eq. (6) is like a risk-less borrowing since it creates a certain future outflow equal to $X_L - X_H$ (Fung et al, 2004). Since the specific cash inflows or outflows are due during the options expiration date, they should be discounted with the risk-free rate. As with the pcp relationship, the box spread does not rely on any options pricing model and it constitutes a pure options market efficiency test since it involves trading in a single integrated market only (Ronn and Ronn, 1989, Fung et al., 2004). According to Bloymeyer and Boyd (1995), the box spread is a trading strategy which is not used frequently but indirectly, floor traders may have a numerous box spread positions in their portfolios. Withal, it is much more applicable in practice mainly because it does not depend on the cumbersome index short selling requisition.

In total, 5225 box spreads were created. The results of this case are summarized in Table 5. As with the pcp relationship, four different cases are considered; a transactions free scenario and three separate scenarios for an individual trader (Ind), a proprietary trader (PrM) and a market maker (MM). In the zero transactions case it can be gauged that the short box spreads are more frequent than long ones. The mean or median profits are quite small since there are is an enormous number of small arbitrage profits in either case. Box spread arbitrage is insignificant in numbers for the individual traders although more frequent compared to pcp violations. Despite that, had the careful individual trader spotted these few arbitrage opportunities then they could have realized significant profits. As concerns the market makers (MM), they could experience twice short box cases rather long ones with a mean value of 2.61 and 3.94 (0.66 and 1.86) index points respectively. The exclusion of quite small profitable box spreads due to the inclusion of transaction costs is the reason for observing larger mean values for market makers relative to the zero transaction strategy. Results for proprietary traders are moderate compared with market makers but significant profitable cases were feasible for them too.

Overall, this strategy reveals that box spread arbitrage is less frequent compared to pcp violations, both in numbers and mean (or median) values. Similar to Ronn and Ronn (1989), the results from Table 5 reveal that options market efficiency holds true for individual traders but considerable arbitrage opportunities exist in the case of market makers.

Of course the options market would be diachronically inefficient if box spread arbitrage opportunities are systematically present through time. From a monthly analysis of the box spread arbitrage strategy (not reported here), it is prominent that severe and numerous long and short positions were present during the early trading history of the FTSE/ASE-20 options contracts. Specifically, from the monthly review of the profitable box spread, economically significant long box (short) spread is exploitable from the market makers perspective only until August 2001 (April 2002). This evidence from the box strategy is in line with other studies which report that options market efficiency improves over time (Ronn and Ronn, 1989, Bloymeyer and Boyd 1995, Ackert and Tian, 2001).

From the analysis here, it can be inferred that market participants in the options market have learned how to exploit the box arbitrage strategy and how to enhance the market efficiency. Despite the fact that many significant box arbitrage opportunities existed during the first months of options trading, their magnitude has decreased with time leaving no room for arbitrage opportunities. Compared to the pcp violations that seem to thrive after October 2001, this form of efficiency is anticipated since box arbitrage is much easier to be applied in practice; all actions take place in the same market, it does not involve the dubious index short selling requisition and it is much cheaper. The steady growth in the volume of options contracts during the last few months of the sample should have been a determinant of this form of efficiency. Of course, the evidence found in here is in stark contrast with the results of Ackert and Tian (2001) who report a large number of box spread violations and rare and insignificant pcp profitable arbitrage opportunities after the inclusion of market frictions.

6. Concluding Remarks

This study considers the efficiency of the Athens Derivatives Market via traditional static arbitrage relations. There is confirmatory evidence that the market was inefficient during the first few months of operation. Significant and persistent put-call parity and box spreads violations conjecture to this assertion. During this period, this market behaved correspondingly to other markets in their first trading steps. The terrorist attacks of September 2001 have been crucial for the market. In the aftermath of this shocking event, all parity violations reversed to comply with the ones found in developed markets.

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Tables

Table 1. Market frictions for the FTSE/ASE-20 Index and derivatives products[a]

Market Friction[b]	**Individuals**	**Proprietary**	**Market Makers**
Q	14%	14%	14%
$k_{SS} = k_{SL}$	1.70%	0.70%	0.40%
k_X	0.50 e.p.c	0.50 e.p.c	0.20 e.p.c
$k_{OS} = k_{OL}$	10 e.p.c	1.20 e.p.c	0.30 e.p.c
$k_{FS} = k_{FL}$	15 e.p.c	1.50 e.p.c	0.30 e.p.c

[a] The numbers in the table refer to the transaction costs, margin requirements and short-sales restriction that apply for the FTSE/ASE-20 Index, Futures and Options for individual and proprietary traders as well as market makers.

[b] m is the rate of availability of short selling proceeds and q the margin requirement. k_{SS} is the cost of selling short the index, k_{SL} is the cost of buying long the index, k_{OS} is the cost of selling short an option, k_{OL} is the cost of buying long an option, k_{FS} is the cost of selling short the futures contract, k_{FL} is the cost of buying long the futures contract, and k_X is the exercise fee for options. The abbreviation with e.p.c. stands for "euros per contract".

Table 2. Put call parity results about the profitable hedges under various schemes of transaction costs and short sales restrictions[a]

Cost[b]	**Zero**	**Ind**	**PrM**	**MM**	**MM(A)**	**MM(B)**	**MM(C)**
	Long put-call parity hedge (conversion)						
Cases	802	1	157	323	323	209	209
% of sample	27.90	0.03	5.46	11.23	11.23	7.27	7.27
Mean value[c]	13.59	16.17	9.97	12.69	12.69	10.85	10.85
***t*-stat**	52.35*	n.a.	25.40*	43.28*	43.28*	32.26*	32.26*
Median value[d]	8.39	16.17	7.07	10.18	10.18	7.85	7.85
***z*-stat**	28.28*	n.a.	12.45*	17.92*	17.92*	14.39*	14.39*
	Short put-call parity hedge (reversal)						
Cases	2072	16	626	1154	761	786	491
% of sample	72.07	0.56	21.77	40.14	26.47	27.34	17.08
Mean value	11.54	4.55	6.95	8.51	7.25	7.60	6.39
***t*-stat**	118.46*	n.a.	52.11*	81.12*	67.25*	63.93*	49.10*
Median value	10.26	3.36	5.49	7.11	5.70	5.36	5.19
***z*-stat**	45.50*	n.a.	24.98*	33.94*	27.55*	28.00*	22.11*

[a] The figures indicate the number and percentage of profitable cases that correspond to either a long or a short hedge of the put-call parity relation, as well as the mean and median values of these profitable hedges expressed in index points.

[b] Cost refers to the total transaction costs paid either by a market makers (MM) or an individual trader (Ind). Zero transaction cost hedges are also considered.

[c] The Chen's modified t statistic is use to test the null hypothesis of a zero population mean using an upper tailed test.

[d] The nonparametric signed rank test is used to test the null hypothesis of a zero population median using a two tailed test.

n.a. refers to non sufficient observations for performing a meaningful test.

* significance at the 1% level.

Table 3. Monthly analysis of the long and short put call parity profitable hedges under zero transaction costs and costs faced by market makers[a]

		Long hedges			Short hedges		
Month	**Year**	**Cases**[b]	**Zero**[c]	**MM(A)**	**Cases**	**Zero**[c]	**MM(A)**
Jan.	2001	88	18.34	13.31*	19	8.84	n.a.[d]
Feb.	2001	39	10.49	4.59*	14	10.00	3.71
Mar.	2001	60	15.01	5.21*	1	0.33	n.a.
Apr.	2001	72	24.17	11.82*	2	31.93	6.08
May	2001	69	33.10	20.37*	0	n.a.	n.a.
Jun.	2001	81	20.05	13.94*	15	6.37	n.a.
Jul.	2001	56	16.52	12.15*	63	11.91	7.01*
Aug.	2001	36	4.80	5.51*	41	8.62	2.29
Sep.	2001	7	3.61	n.a.	70	12.53	10.70*
Oct.	2001	0	n.a.	n.a.	69	17.47	5.65*
Nov.	2001	41	4.41	n.a.	57	8.30	0.67*
Dec.	2001	36	9.53	2.35*	18	8.52	n.a.
Jan.	2002	21	2.42	n.a.	140	6.86	n.a.
Feb.	2002	39	5.07	n.a.	58	3.29	n.a.
Mar.	2002	38	5.00	n.a.	31	4.79	n.a.
Apr.	2002	21	2.56	n.a.	103	15.55	5.34*
May	2002	13	2.96	n.a.	115	11.45	2.90*
Jun.	2002	11	1.63	n.a.	103	10.37	3.14*
Jul.	2002	22	1.37	n.a.	159	9.50	2.56*
Aug.	2002	20	0.82	n.a.	140	7.03	2.86*
Sep.	2002	19	2.79	n.a.	169	7.58	6.09*
Oct.	2002	7	1.79	n.a.	155	15.34	8.19*
Nov.	2002	4	1.99	n.a.	121	8.90	2.47*
Dec.	2002	2	3.72	n.a.	87	16.87	9.44*
Jan.	2003	0	n.a.	n.a.	125	22.02	12.31*
Feb.	2003	0	n.a.	n.a.	100	14.69	6.06*
Mar.	2003	0	n.a.	n.a.	97	14.61	7.57*
	Total	**802**			**2072**		

[a] The figures in the table represent the monthly cases of a long (conversion) or short (reversion) profitable hedge under zero transaction costs and under the cost faced by market makers with short sales constraints.
[b] These are the monthly long or short hedges and under zero transaction costs and are irrelevant with the monthly hedges tabulated for the market makers.
[c] All hedges that correspond to more than 10 cases, exhibit significance at the 1% level in an upper-tailed Chen's modified *t*-test under the null hypothesis of a zero population mean.
[d] n.a. refers to months that a profitable hedge does not exist.
* correspond to more than 10 hedges that exhibit significance at the 1% level in an upper tailed test under the null hypothesis of a zero population mean using the Chen modified *t*-test.

Table 4. Regression analysis based on the put-call parity relation[a]

Period	Obs.	β_1	*t*-stat.	β_2	*t*-stat	R^2
2001-2003	2874	-0.0062*	-26.45	0.9833*	-4.53	99.10
Jan. – Jun. 2001	459	0.0093*	20.56	0.9782*	-2.83	97.25
Jul. – Dec. 2001	493	-0.0032*	-6.64	1.0104	1.63	98.11
Jan. – Jun. 2002	693	-0.0058*	-22.34	0.9840*	-3.17	98.21
Jul. – Dec. 2002	904	-0.0100*	-34.66	0.9965	-0.86	98.50
Jan. – Mar. 2003	321	-0.0216*	-37.59	1.0160	1.50	96.59

[a] The numbers correspond to the linear regression analysis estimates and statistics to validate the put-call parity for the whole period and for five different sub-periods. *t*-stat for β_1 concerns the null hypothesis of zero intercept and for β_2 concerns the null of a unity slope.
* significance at the 1% level in a two-tailed test.

Table 5. Box spread results about the profitable hedges under various schemes of transaction costs[a]

Cost[b]	Zero	Ind	PrM	MM
			Long box spread	
Cases	2190	51	388	513
% of sample	41.91	0.98	7.43	9.82
Mean value[c]	1.04	12.15	4.24	3.94
***t*-stat**	37.05	14.26	30.69	41.02
Median value[d]	0.07	8.65	1.90	1.86
***z*-stat**	46.78	n.a.	19.65	22.61
			Short box spread	
Cases	3035	82	391	871
% of sample	58.09	1.57	7.48	16.67
Mean value	0.91	8.01	4.65	2.61
***t*-stat**	54.71	20.30	43.85	46.96
Median value	0.13	4.25	2.15	0.66
***z*-stat**	55.07	n.a.	19.72	29.48

[a] The figures indicate the number and percentage of profitable cases that correspond to either a long or a short box spread position, as well as the mean and median values of these profitable hedges expressed in index points.
[b] Cost refers to the total transaction costs paid either by a market makers (MM), a proprietary (PrM) or an individual trader (Ind). Zero transaction cost hedges are also considered.
[c] The Chen modified *t* statistic is use to test the null hypothesis of a zero population mean using an upper tailed test.
[d] The nonparametric signed rank test is used to test the null hypothesis of a zero population median using a two-tailed test.
n.a. refers to non sufficient observations for performing a meaningful test.
* significance at the 1% level.