Market Efficiency Test Of Australian Options Market Using Put Call Parity Analysis

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Abstract

Title: Market efficiency test of Australian Options Market using put call parity analysis.

Author: Lee Eng Kiang, Peter

The aims of this thesis is twofold. The primary objective is to test the market efficiency of Australian Options Market (AOM) using the put call parity model. In addition, empirical evidence on the put call parity model is also gather.

The put call parity model specified a deterministic relation between the prices of calls and puts. In particular, the put call parity model specifies an upper and lower boundary conditions. A breach in the put call parity model result in arbitrage opportunities which is inconsistent with a efficient market. Four companies share options traded in AOM over a six month period, were used to test whether the put call parity pricing relation was maintained.

The thesis is divided into five chapters. Chapter 1 spell out the aims of the thesis and a brief overview of the structure of AOM. This is follow by a literature review on previous studies of put call parity analysis. Chapter 3 describe the methodology and hypothesis tested in the current study. The findings of the test are reported in Chapter 4. The final chapter summarizes the methodology and findings of this thesis.

The findings of the thesis support the hypothesis that the AOM is efficient over the period study. Violations of put call parity boundary conditions were infrequent. None of these violations yield economic profits for potential arbitragers. Lower boundary violations occur more often than upper boundary violations. In addition, the lower boundary violations appear to be affected by companies specific effect, time to maturity effect and degree in which options is "in the money".
"I certify that this thesis does not incorporate, without acknowledgment, any material previously submitted for a degree or diploma in any institution of higher education and that, to the best of my knowledge and belief, it does not contain any material previously published or written by another person except where due reference is made in the text."

Date: 6/4/93
Acknowledgements

I wish to thank the following people for their constant support and encouragement.

Frank Hong and Jenny Phang, without their support and encouragement, this thesis will never be completed on time.

The wonderful lecturers in the Finance Department, Raymond Boffey, Terry Ord, Roy Pearce, Graham Robson and Mark See, for their wisdom and constructive comments.

I would also like to thank Professor Robert Brown of Monash University for taking the time to answer some of my queries.

My housemate, Gerard Tan, for helping me collect the data and keeping my sanity.

Finally, I like to dedicate this thesis to my mother.
CHAPTER 1
INTRODUCTION, OVERVIEW AND PURPOSE

Introduction and Definitions

An option is a contract in which the seller (writer), for a certain sum of money (option premium), gives the buyer the right, but not the obligation, to buy or sell a specified number of financial instruments or other commodities at a fixed price (exercise price) within a specified time (terminating at expiration date). This right (rather then obligation) allows an investor the ability to obtain unlimited profit while limiting the loss to the option premium. There are two different categories of option. A call option gives the holder of the option contract the right to buy, while a put option gives the holder the right to sell.

For the period January-December 1991, there were 25 to 29 company stocks over which call and put options were traded in the Australian Options Market (AOM). The stock options traded are of the "American" as distinct from the "European" type. American options can be exercised anytime until the expiration date while European option can only be exercised on the expiration date.

The primary aim of this thesis is to examine the market efficiency of the AOM through the pricing relationship between call and put options. More specifically, the relationship tested is the put-call parity that was first proven by Stoll in 1969. A breach of "put-call parity" would allow an investor to obtain an arbitrage profit, which is inconsistent with an efficient market. Additionally, empirical evidence on the parity relation in Australia is collected, as most past studies have concentrated only on absolute pricing models such as the Black and Scholes model.

1 Beside share options, the other types of option currently traded in Australia are bond options, currency options, commodity options and share price index options. (Park et al. Schoenfeld 1992,p. 119)
2 Gai and Brenner (1986) credited Castelli (1887) for first describing the parity relation in the book The Theory of "Options" in Stocks and Shares.
Structure of the Australian Options Market

Before examining the efficiency of the AOM, it is useful to take a brief overview of the structure of the market. The AOM began trading options in February 1976 as the first organised option exchange outside North America. The initial options traded were call options on company stocks of BHP, CSR and WMC. It was not until September 1982 that the AOM introduced put options. The AOM structure was modelled after the Chicago Board of Options Exchange (CBOE) with a system of registered traders. According to Peak Markwick (1986), registered traders are allowed to trade on their own accounts which ensure orderly and continuous trading opportunities. Continuity of trade is established through asking registered traders to make a market in an option or alternatively trade in at least one contract, either buying or selling, to the market they had made. These also ensure that appropriate price relationships are maintained in the option series even in a thin market.

The other innovation that ensures orderly and continuous trade is the board broker. A board broker is an employee of the Option Clearing House (OCH) and is not permitted to trade on his own but only on client orders placed with him at a price limit. Orders are executed on a first come, first serve basis, regardless of size. This ensures that all investors have equal access to the market.

Furthermore, operators that trade among themselves have to trade at prices within the market prices set by registered traders, and board brokers have first priority. The market prices set by registered traders are the daily quoted bid/ask spread. These are the prices where registered traders stand ready to buy an option contract at the bid quote or sell an option contract at the ask quote. By ensuring board brokers’ client orders are executed first before trading between operators are allowed, also help ensures competitive prices are maintained.
Purpose of Study

The aim of the study is twofold. The first is to test the efficiency of the AOM; the second to provide empirical evidence on the put call parity relation. The test of market efficiency conforms to Fama's (1970) classification of the weak form market efficiency hypothesis since the test is on the pricing relation and not on the profitability of traded based on publicly or privately available information.

Test of the efficiency of the Australian Options Market

There are important implications of a market being found to be efficient. The most notable is, of course, that past prices fully reflect all relevant information in an efficient market and it thus serves as an efficient allocator of scarce resources. As noted by Stoll and Whaley (1992, p. 12) "Option markets encourage increased research and analysis... Insofar as increased analysis and increased interest improves the quality of prices, resources will be allocated more efficiently." In general, Cox and Rubinstein (1985) also argued that an efficient options market provides useful source of information for important economic decisions. This is because options prices contain implicit predictions about future events such as, future volatility, cash dividends and interest rates. Additionally, options market provides a mean toward an economy with "complete market". A complete market is where any securities returns can be duplicated by existing securities. A complete market, by providing a wide variety of securities returns, further enhances the efficiency in resource allocation.

Furthermore, almost all tests of pricing models use efficient markets as a starting point. This is due to the fact that tests of a pricing model are joint tests of market efficiency and the pricing model. The put-call parity does
not fall into the trap of joint hypothesis tests as it only specifies a distinct price relationship between the prices of call option, put options and the underlying stock. Gray (1989, p.152) thus argued that, "[in] examining put-call parity, it may be possible to directly test the efficiency of an options market, since the relative pricing of put and call options is being examined, rather than the absolute price of an option." Similar arguments can also be found in articles by Loudon (1988, p. 54) and Taylor (1990, p. 205).

Assuming data accuracy and market synchronisation, an ex-ante violation of this relationship would allow investors arbitrage opportunities and is therefore prima facie evidence of an inefficient market and not the result of pricing model misspecification. The assumption of an efficient market allows researchers to conclude that any deviation between the observed price and the model price is due solely to the pricing model, or vice versa. Thus, the findings of a test of the efficiency of an options market test also have important implications for past and future tests of option pricing models. Though it is not suggested here that the study will give an irrevocable statement of whether the option market is efficient or not. No such test is possible. Rather, the study hopes to provide additional evidence for the support or rejection on the assumption of market efficiency.

**Test of put-call parity**

The second purpose of the study is to empirically test whether the Australian data support the put-call parity relation. Almost all finance texts which have a chapter on options will contain a section on the put-call parity model. The other prominent feature of option theory is of course the Black and Scholes option pricing model. While abundant research has been done on the validity of the Black and Scholes option pricing model, the research
on put-call parity has been limited. As noted by Kochman and Hood (1986), tests of option market efficiency have concentrated on the correspondence between market and model prices.\(^3\)

The Australian research on put-call parity is generally limited to three articles and one unpublished working paper. The three articles are those of Gray (1989), Loudon (1988) and Taylor (1990). The working paper by Brown and Easton (1992) does not really provide new empirical evidence on the parity relation in the AOM. Rather it found that the evidence collected from the Loudon and Taylor articles was in direct conflict and attempted to reconcile the results of the two articles. They found that due to certain methodology and calculation mistakes in Taylor's article, there is strong reason to disregard Taylor's results. Thus, in effect there are currently only two research studies that provide empirical evidence on the parity relation.

In addition, the period covered by the above three articles encompassed the years prior to 1987. As noted in Taylor's article (1990, footnote 6), in the period examined in his study institutional restrictions on the short selling of stock were in force. The Australian Stock Exchange amended the rules to allow for short selling from September 1986. As short selling of stock is one of the essential features in the enforcement of the "upper boundary" of the parity relation, it would be interesting to see how the change in institutional structure has affected the applicability of this parity relation.

\(^3\) The study of Black and Scholes option pricing model in Australian context includes Brown (1978), Castagna and Matolese (1982, 1983) and Chieralla and Hughes (1975a, 1975b). The empirical tests of Black and Scholes option pricing model in America are too numerous to be listed though Golib's (1983) article A survey of empirical tests of option pricing models does provide a good review of past studies.
The other new development in the AOM not covered in previous studies of put-call parity analysis was the introduction of "spot options". Spot options, as distinct from the *regular* options, expire within the month rather than following the quarterly expiration cycle of the *regular* options. This has the effect of increasing the number of option series available to investors as they are now not restricted to just the quarterly expiry option series. As a result, the pricing data for this study also increased from just the *regular* quarterly expiry option series to new option series.

Finally, the various effects on put-call parity relation are also investigated. The various effects that will be examined include:

i) effect of using different discounting methods and risk-free estimates;

ii) effect of different firms and sectors;

iii) effect of time to maturity and

iv) effect of the options being "in the money".

The purpose of the thesis is thus to test the efficiency of the AOM and, in addition, to provide additional empirical evidence on the validity of the put-call parity theorem in Australia.
CHAPTER 2
LITERATURE REVIEW

Introduction

The literature survey begins with finding an appropriate definition for the term "market efficiency". Though most finance academics are familiar with Fama's classification of the efficient market hypothesis (EMH), there is now a school of thought that contends that Fama's classification is inadequate or inappropriate. In a recent NATO research workshop on financial market efficiency, Guimaraes, Kingsman and Taylor (1988) documented the unsuccessful attempt to get a clear consensus on a common definition of efficiency. As noted by Guimaraes et al., "Some participants [of the workshop] argued for particular definitions whilst others regarded efficiency as a matter of degree or as a state that prevailed at some times but not at others." (p. 3) Nonetheless, Guimaraes et al. point out that without a precise definition of market efficiency, it is difficult to formulate research designs for testing the efficiency hypothesis and also draw acceptable conclusions from the research. Thus, the first task is to choose an appropriate definition. The theoretical proof and development of the parity relation are then reviewed in the following section. Previous empirical studies on the parity relation and option market efficiency tests are reviewed in the last section.

Definition of efficiency

The study of financial market efficiency has a long and illustrious history. The first use of the term "efficient market" was credited by Ball (1988) to Fama, Fisher, Jensen and Roll in their 1969 article. Since then the definition of efficient market has gone through a series of refinements and developments. Though there are no
clear consensus on a precise definition for market efficiency, Guimaraes et al. do point to information efficiency as a common essential starting point.4

There are generally two alternative definitions of information efficiency. These are broadly split into the 'Chicago school' or 'empirical' view and the 'Berkeley school' or 'information economics' view. Chicago school definition of efficiency treats the market as an entity in its own right and ignores individual investors' behaviour. That is, the market is personified and studied as an entity alone. How individual investors' behaviours combine to influence market efficiency is left in a "black box". Berkeley school in contrast begins by looking at individual investors and how their aggregate behaviours influence the efficiency of the market. Thus, it can be said that the former begins with a macro level while the latter works its way up from the micro level.5

Ball argued against the Berkeley school in that the more formalised definition of looking at individual investors does not provide any further useful insight compared to the Chicago school of looking at the market as an entity. Also from a theoretical viewpoint, it suffered from confusion between properties of information and properties of markets. The Berkeley school is actually comparing a market which has costless information to the actual market (properties of information) and not testing the degree to which the actual market differs from an ideal market (properties of market). There is another argument against using the Berkeley school of definition in this study. The set of individual investors for stock market efficiency is much more easily identified than the set of individual investors required to test option market efficiency. This is due to the fact that the values of

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4 The various forms of efficiency are, exchange efficiency, production efficiency and information efficiency. Exchange efficiency tests the efficiency of converting production to consumption (property of consumption markets) while production efficiency tests how efficient the production organised (property of production) and information efficiency tests how quickly prices reflect all relevant information (property of information and securities prices).

5 For a more in depth discussion on the two schools of thought see Guimaraes et al. (p. 3-5) and Ball (1989, p. 32-35).
options are derived from stock prices. A stock market efficiency test can concentrate on the set of investors in that single market but option market efficiency has to take into account investors in both the stock and the option markets. If the option market is found to be inefficient, such inefficiency could be driven either by individuals investing only in the option market, or by stock market investors, or by investors who invest in both stock and option markets. The tasks of separating and analysing this set of investors' behaviour are difficult. The parity model further compounds the problem when one considers that it involves three securities. (The call option, the put option and the underlying stock.) Thus, individual investors' behaviour is not analysed rather, the efficiency of the option market as an entity is tested.

Even if the Chicago school's definition is accepted, further refinement is required. As noted by Guimaraes et al. (1988), the definitions of efficiency by both Chicago and Berkeley schools are statement of economic theory which do not directly address the question of a precise testable measure of market efficiency. That is, both Chicago and Berkeley schools only define the term efficiency but do not specified a measure of efficiency that is testable. The testable definition of efficiency used in this study is that of Jensen (1978, p.96):

"A market is efficient with respect to information set \( \Phi_t \) if it is impossible to make economic profits by trading on the basis of information set \( \Phi_t \). By economic profits, we mean the risk adjusted returns 'net of all costs'."

Ball (1989, p. 38-39) heavily criticises this definition from the sufficiency viewpoint. He noted that a market that does not fully reflect information will be deemed efficient, using Jensen's definition, if no trading rules can be devised to exploit this. In addition, he pointed out that there are different transaction costs for different groups of investors. For example, brokers or specialists face much lower
transaction costs than normal public investors. The problem is to identify which set of investors' transaction costs should be used.

The defence of Jensen's efficiency definition is put forward by Guimaraes, et al. (1988). They argued that trading profits net of properly defined transaction costs should be regarded as a necessary condition for markets to be deemed efficient. It is necessary that an efficient market does not allow economic profits but not sufficient to say that since no economic profits are made in the market then the market is efficient. Thus the non existence of economic profits only provides partial evidence for the test of market efficiency.

As the parity relation is based upon an arbitrage argument, transaction costs are highly relevant and thus should be explicitly considered in testing market efficiency. Though it should be noted that transaction costs will only explain why arbitrage opportunities is not exploited but not why arbitrage opportunities exist. The highest degree of efficiency would result when the set of investors which had the lowest transaction costs are unable to exploit any economic profit and since there are trading rules that can be devised to exploit opportunities for economic profits, Jensen definition is appropriate in this study. The trading strategies for exploiting breach in parity relation are conversions, reversals and box.

**Standard Put-call Parity**

The standard put-call parity model was first proven by Stoll (1969). The assumptions of the model as identified by Brown and Easton (1991, p. 2) are:

(i) the put and call options relate to the same underlying share and the options have common exercise prices and expiration dates.
(ii) Trading is "frictionless", which means that no transaction costs or taxes arise, and simultaneous trading of the three securities and a risk free asset is possible.

(iii) The options are of the European type and the stocks pay no dividends during the life of the options.

The parity model can be proven when one considers the possible end of period cash flows of a call option and a portfolio consisting of the underlying stock, the put and borrowing at the risk free interest rate $r$. The two portfolios and cash flows for a single period are constructed in Table 1. As both strategies yield the same cash flow under similar market states, the initial investment must be the same. If either of the portfolios is under- or overpriced relative to the other, an investor can sell the relatively overpriced portfolio and buy the underpriced to lock in a risk free profit. Therefore in a perfect market the following relation must exist:

$$C = S_0 + P - K(1 + r)^T \ldots \ldots \ldots (1)$$
$$C = S_0 + P - Ke^{-rT} \ldots \ldots \ldots (2)$$

where $C$ - call price;
$S$ - stock price;
$P$ - put price;
$K$ - exercise price (must be the same for both put and call);
$r$ - risk free interest rate;
$e$ - exponential function;
$T$ - time to maturity.

Equation (1) uses a discrete discounting factor while equation (2) is the continuous discounting counterpart. The two differ slightly in the assumption. The former assumes that assets are traded in discrete time periods while the latter assumes

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6 Stoll's (1939) original proof used vector notation to show that the investor that writes call (put), goes long (short) in the underlying stock and buys the equivalent put (call) is in fact not holding any position in either the stock or option market. Most standard finance texts generally use the portfolio cash flow payoff to illustrate the parity relation. The latter method was chosen as it is easier to comprehend.
assumes that assets are traded in discrete time periods while the latter assumes continuous trading. Since put call parity require simultaneous trading of the three assets, a continuous discounting factor would be more appropriate. This is because simultaneous trades of the three assets are more probable when trading is continuous than in discrete interval. Given that in a discrete trading world, the three assets trading interval must coincide before simultaneous trade is possible while continuous trading do not have to worry about the trading interval.7 Nonetheless, the study will employ both discrete and continuous discounting factors in testing the market’s efficiency.6

Table 1

**Proof of standard put-call parity (European non-dividend paying stock options)**

<table>
<thead>
<tr>
<th>Portfolio</th>
<th>Terminal Value (T)</th>
<th>Initial Value if $S_T &lt; K$</th>
<th>Initial Value if $S_T &gt; K$</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Portfolio A</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Buy Call</td>
<td>$-C$</td>
<td>$S_T - K$</td>
<td>0</td>
</tr>
<tr>
<td><strong>Portfolio B</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Buy Stock</td>
<td>$-S_0$</td>
<td>$S_T$</td>
<td>$S_T$</td>
</tr>
<tr>
<td>Buy Put</td>
<td>$-P$</td>
<td>0</td>
<td>$K - S_T$</td>
</tr>
<tr>
<td>Borrow at interest rate $r$</td>
<td>$+Ke^{-rT}$</td>
<td>$-K$</td>
<td>$-K$</td>
</tr>
<tr>
<td>Total</td>
<td>$-S_0P + Ke^{-rT}$</td>
<td>$S_T - K$</td>
<td>0</td>
</tr>
</tbody>
</table>

(Adapted from Levy and Samat 1984, p. 579)

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7 For further discussion on the difference between discrete and continuous analysis model see Haley and Schall (1979, pp. 239-242).

8 For the sake of brevity only, continuous time analysis model is used for subsequent discussion.
Put-call parity for American options and dividend paying stocks

The problem with the above model is that it is only applicable to European options (where early exercise is precluded) and the stocks do not pay dividends (assumption 3). The options traded in the AOM are of the American type and the stocks do pay dividends. Thus, to use the put-call parity model in the Australian context, assumption 3 has to be relaxed or modified.

Further developments of the parity model had to be credited to Merton (1973) and to Klemkosky and Resnick (1979). Merton extended the model to incorporate the early exercise feature of American type options. Early exercise of call options is not a problem as it is not rational for investor to exercise early. (As long as the stock is not paying a dividend or the options are “dividend payout protected”, it would never be more profitable to exercise the call options than to trade it in the market.) In the case of put options, however, exercise before maturity can be rational. Given the possibility of puts being exercised, the standard parity model becomes a boundary condition. Klemkosky and Resnick then extended the parity model to include the effects of dividend payout. If it can be assumed that the dividend amount is known with certainty, the extended parity model will include the present value of the certain dividend. The extended put-call boundaries condition with its proof is reproduced below:

\[
C - S + K + D/(1+r)^T \geq P \geq C - S + K(1+r)^T \quad \quad (3)
\]

\[
C - S + K + D e^{-rT} \geq P \geq C - S + Ke^{-rT} \quad \quad (4)
\]

where \( D \) is the present value of the single certain dividend payout within the duration of the option and the other terms are as previously defined.

\[9^{\text{th}}\] If the dividend amount is unknown, then the new term will be the present value of the expected maximum dividend payout.
Upper Boundary Proof\textsuperscript{10}

The upper boundary restriction of a put value is given by \( C - S + K + D e^{-rT} \geq P \).
Rearranging the equation yields \( C - S + K + D e^{-rT} - P \geq 0 \). The upper boundary condition can be proven by considering a portfolio constructed by writing the put, buying the call, short selling the stock, buying \( D \) amount in the form of a risk free bond and placing amount \( K \) in a savings account.\textsuperscript{11} This is illustrated in Table 2. When the stock pays the dividend, liquidate \( D \) to compensate dividends paid as the stock was short. If the short position is closed off before expiration or if less than maximum dividends are actually paid, the investor with the above portfolio would have an added bonus sum from the \( D \) risk free bond source. (See Ex Div Day column.)

If all of the security positions stay open until expiration, (ie no early exercise) the cash flow at maturity will be a positive amount regardless of the terminal stock price. (See the Terminal Value columns.) In this case, however, there is the further possibility of early exercise of the put option by the holder. This is covered by withdrawing the amount \( K \) from the savings account to pay for the stock when the put is exercised early. The stock received can then be used to close out the short sale. The investor still has the call option valued \( C_t \) and accumulated interest on \( K \). (This is illustrated in the Intermediate Value column.) Thus, regardless of whether the dividend is paid or whether there is early exercise of the put option, the net terminal value of the portfolio will always be positive and the initial value must also then be positive.

\textsuperscript{10} The upper and lower boundary proof are adapted from Cox and Rubinstein (1985, p. 152-154).
\textsuperscript{11} If dividend is unknown, the required risk free bond amount will be \( D^+ \), which is the maximum expected dividend payout.
Table 2
Upper boundary proof of put-call parity for American stock options \((C-S+K\cdot e^{-\rho T}-P\geq 0)\)

<table>
<thead>
<tr>
<th>Position</th>
<th>Initial Value(^{1,2})</th>
<th>Intermediate Value</th>
<th>Terminal Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sell America Put</td>
<td>(P)</td>
<td>(-K + S_T)</td>
<td>(-K + S_T)</td>
</tr>
<tr>
<td>Buy America Call</td>
<td>(-C)</td>
<td>(C_T)</td>
<td>(0)</td>
</tr>
<tr>
<td>Short Sale Stock</td>
<td>(S)</td>
<td>(-S_T)</td>
<td>(-S_T)</td>
</tr>
<tr>
<td>Saving Account K</td>
<td>(-K)</td>
<td>(K e^{-\rho T})</td>
<td>(K e^{-\rho T})</td>
</tr>
<tr>
<td>Risk free Bond D</td>
<td>(-D e^{-\rho T})</td>
<td>(D)</td>
<td></td>
</tr>
</tbody>
</table>

\[\text{Net Portfolio Value: } P - C + S - K \cdot D e^{-\rho T} = 0, \quad C_T + K(e^{-\rho T} - 1), \quad K(e^{-\rho T} - 1)\]

(Adapted from Stoll and Whaley (1992, p. 318)

Lower Boundary Proof

The lower boundary is given by \(P \geq C - S + K e^{-\rho T}\) or \(P - C + S - K e^{-\rho T} \geq 0\). (See Table 3.) The designated portfolio would consist of buying the put, writing the call, buying the stock and borrowing amount \(K e^{-\rho T}\) by selling zero-coupon bonds with time \(T\) until maturity.\(^{13}\) Again this portfolio should yield positive amounts at the end of the day. If there is no early exercise of the call option, the portfolio is the

\(^{12}\) Note the signs of the initial value are inverse because the net portfolio value represent the costs of investing.

\(^{13}\) Stoll and Whaley's (1992) proof of the lower boundary include a redundant borrowing of the amount of expected dividend payout. If dividend is received (which will occur if call is not exercised or exercised after ex-div day), then the portfolio holder will receive a added bonus for the amount of the dividend plus the terminal value. On the other hand, if dividend is not received (call exercised prior to ex-div day), then the portfolio holder will still receive the terminal value but without the bonus dividend amount. Thus, the terminal value will still be positive regardless of whether the dividend is received.
combination of the standard put-call parity portfolio of A and B discussed previously. Since the investor is now selling the call option portfolio and buying the opposite position he would expect zero gain or loss in term of capital value.

Nonetheless, as he is now dealing with a dividend paying stock, the investor will receive the dividend (since the stock is now bought long) and will gain from the dividends received and interest accumulated if the dividend is put in a savings account provided that the call is not exercised early. If the call is exercised before expiration date, then he will deliver the stock and get the exercise price \( K \). The \( K \) amount will be used to redeem the bonds and, since interest rates are always positive, there will always be enough to do this and there may be a positive amount left over. In addition, the investor still has a put option contract and possible dividend receipt if early exercise occurs after the ex-dividend date. Thus, the net end-of period payoff is again positive regardless both of the amount of the dividend or of whether early exercise of the call option occurs.

Table 3

Lower boundary proof of put-call parity for American stock options

<table>
<thead>
<tr>
<th>Position</th>
<th>Initial Value</th>
<th>Intermediate Value</th>
<th>Terminal Value</th>
<th>Day</th>
<th>Early (t)</th>
<th>Put Exercised</th>
<th>Put Exercised at maturity(T)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sell America Call</td>
<td>C</td>
<td>-(S_t-K)</td>
<td>0</td>
<td></td>
<td></td>
<td></td>
<td>-(S_t-K)</td>
</tr>
<tr>
<td>Buy Stock</td>
<td>-S</td>
<td>D</td>
<td>S_t</td>
<td></td>
<td></td>
<td>S_t</td>
<td>S_t</td>
</tr>
<tr>
<td>Buy America Put</td>
<td>-P</td>
<td>P_t</td>
<td>K-S_t</td>
<td>0</td>
<td></td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Borrow Ke^{-T}</td>
<td>Ke^{-T}</td>
<td>-Ke^{-T(t-t)}</td>
<td>-K</td>
<td></td>
<td></td>
<td>-K</td>
<td>-K</td>
</tr>
</tbody>
</table>

Net Portfolio Value: \( C - S_t + P_t + K(e^rT - 1) \)

(Adapted from Stoll and Whaley (1992, p. 319))
Previous studies of put-call parity using America data

The literature review of past studies of put-call parity will concentrate on use of the model to test option market efficiency. Other research papers have used the model for purposes other than test of market efficiency. This is incompatible with the purpose of the current study as they all begin with assumption of market efficiency and therefore will not be reviewed here.14

Stoll (1969)

Following the theoretical proof of the parity model, Stoll (1969) then went on to empirically test the parity model using Over-the-Counter (OTC) options market data.15 The data source used were the weekly price submissions by the Put and Call Dealers Association to the Securities Exchange Commission. These included option series on 15 Regular companies and 10 New Business companies option series with maturity of 90 and 190 days. The period covered was two years from 1966-67 (or 104 weeks of put and call prices) for Regular companies option series and one year 1967 (or 52 weeks) for the New Business companies option series. Given that the price submissions are only nominated prices and not market determined prices, only actively traded option series were included as these prices are more reliable. The parity models tested were of the limited case where the stock price equals exercise price and the options are priced

14 Examples of the other uses of the parity model are the examination of implied interest rate in Brenner and Galai (1986) and Frankfurter and Leung (1991) and an examination of early exercise in option prices by Zivney (1991).

15 The first listed option market, Chicago Board of Exchange was not established until 1973.
relative to the stock price. Regression analysis of the following form was tested:

\[ c = a_0 + a_1 i + a_2 p + u \]

- 0.25 for the 90 day maturity and
- 0.50 for the 190 day maturity

The model is supported when \( a_0 = 0 \), \( a_2 = 1 \) and \( a_1 = \)

The general results were that there was a significant positive relation between the relative call and put prices and coefficient \( a_2 \) was approximately 1 as predicted by the model. But the constant coefficient \( a_0 \) was significantly non-zero and the interest coefficient \( a_1 \) was also different from the predicted value of 0.25 or 0.5. The significant deviation from zero of the constant term \( (a_0) \), was hypothesised to be due to \( a_0 \) picking up interest cost not reflected in the coefficient of treasury bill rate \( (a_1) \). The deviation of \( a_1 \) from predicted value was explained away by Imperfections in the data and the effects of interest rate being inconsequential compared to transaction costs. Stoll concluded thus that "by and large the theory is supported by time series and cross-section regression analysis" (p. 823)

**Gould and Gala! (1974)**

Gould and Gala! (1974) also tested the model using OTC option market data. They noted that Stoll's inference that the standard parity formula applied equally both to American and European options was false. They therefore tested the parity model in terms of a boundary condition

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16 The parity model tested is \( c = p + i \), which is a special case when stock price equals exercise price. The general model was \( C = S + P - E(1+i) \). Substituting \( S=E \) and dividing both sides by \( S \) yields, \( C/S = 1+P/S - 1/(1+i) \). Using small \( c \) to denote the relative price, the model thus predicts \( c = 1 + p - 1/(1+i) \). Then by noting that \( 1 - 1/(1+i) = i/(1+i) \approx i \), the model thus predicts that \( c = p + i \) where \( i \) is the risk free rate stated on an annual basis. The predicted coefficient of \( a_1 = 0.25 \) for a 90 day maturity is because to convert the annual rate to a 90 day rate, the rate is adjusted by dividing 90/360. Similarly for 190 day, \( a_1 = .5 \) or 190/360.
(C-P)/S\leq i/(1+i) instead of an equilibrium model. Furthermore, they argued that regression technique is inappropriate for testing the existence of arbitrage profits since regression is based on averaging while tests of market efficiency are concerned with outliers. They tested the model by using price observations to calculate the formula (C-P)/S - i/(1+i). The model is then supported if this yields a negative amount. Their major data source used was again the weekly price submissions of Put and Call Dealers for period 1967-69 but in addition to these nominal prices they also used actual option prices obtained from the diaries of an option broker for the period 1966-69. Their findings showed a surprisingly large number of positive results that represented potential profit opportunities dependent on the transaction costs. Many of these abnormal profits were only exploitable by members of the New York Stock Exchange. Nonetheless, the fact that members of NYSE had apparent exploitable abnormal profits was found to be inconsistent with the model. They therefore concluded that "the model is not supported unless rather large transactions costs are included ... [which] raise troublesome questions as to whether there were unexploited profit opportunities in the options markets at least during the 1967-1969 period." (p.105)

Klemkosky and Resnick (1979 and 1980)

A test of the put-call parity model using organised options market\textsuperscript{16} data was performed by Klemkosky and Resnick (1979, 1980). It should be noted that the parity model used by Stoll did not consider the effect of dividend payout. Klemkosky and Resnick (1979, p. 1149 in footnote 14), argued that

\textsuperscript{16} Organised, listed or registered options market are markets where options are traded in a centralised and standardised manner as in the CBOE and AOK. This is distinct from the OTC market where options are traded in a non-standardised manner and only among two parties without the intermediation of the central clearing corporation. For a discussion on the difference between the two markets, see Gastineau (1988, p. 22-23).
the OTC models should have included a dividend term since OTC options are only partially dividend payout protected. The effect of a dividend is more dramatic in organised options markets as listed options are not dividend payout protected at all. Klemkosky and Resnick thus extend the parity model to incorporate the dividend payout. Their data consisted of CBOE, the American and the Philadelphia Stock Exchange put and call options on fifteen companies traded over the period July 1977 to June 1978. They formed two simultaneous hedged portfolios. The long hedged portfolio consist of selling a call and buying a synthetic call position and the short hedged portfolio involved selling a put and buying a synthetic put position. The effect of the long and short hedges are that the investor does not have an open position in the option market and should therefore not earn any economic profit at all. Of the 608 hedges, they found 234 profitable hedges. When they allowed for transaction costs, arbitrage profits were found to exist only for member firms. They thus concluded that "the empirical results of the models tested are consistent with put-call parity theory and thus support this aspect of efficiency of registered options markets." (p. 1154)

It should be noted though that the 1979 paper was an "ex-post" test where they assumed that an arbitrage opportunity could be executed immediately while in the 1980 test they lagged the arbitrage trading by 5 and 15 minutes to form an ex-ante test. In the ex-ante test Klemkosky and Resnick(1980) found that the "tendency for ex ante profitability to be less than ex post profitability and for price corrections to take place rapidly enough to eliminate most if not all of the opportunity for economic profits. " (p. 377)

18 The hedge was formed by including only observation that have put, call and underlying securities traded within one minute of each other.
19 The synthetic call and put position are replicated by taking the opposite position in the parity formula. Example in the European non-dividend paying parity, to replicate the call position is by constructing portfolio A.
Phillips and Smith (1980)

Before leaving the American arena, an article by Phillips and Smith (1980) highlights the importance of incorporating all transaction costs in tests of option market efficiency. They argued that most studies only considered explicit transaction costs (such as, commissions, costs of floor trading and clearing fees) but ignored implicit transaction costs. The implicit transaction cost they explored was the bid ask spread. By including the implicit cost of this spread, they found that most of the arbitrage opportunities in past studies were eliminated. Even if the arbitrage opportunities still exist after netting off bid ask spread, they argued that the cost of obtaining an exchange seat may serve to be the reason for the observed abnormal profit.

Previous studies of put-call parity using Australia data


Loudon (1988)

Loudon conducted the first market efficiency test of AOM using the put-call parity model. His data source consisted only of BHP options trading data in the Register of Sales for the period 1985. The Risk free rate was estimated from 13 and 26 week Treasury notes. He found 38.5% of the sample violated the lower boundary condition while only 1.5% of the sample violated the upper boundary condition. He found this result surprising as, a priori, the theoretical upper bound was more likely to be breached than the lower. This is because the upper boundary requires a short sale of stock.
which was not permitted at the time, and also the lower boundary does not contain the uncertain dividend term and should therefore be stricter. He also tested the sensitivity of the violation rate to interest rate by proportional and constant increase of the T-note rate and found that the observed violation result is unchanged by these adjustments. To examine the effect of friction in the market, he examine the effect of price non-simultaneity, stock price range (transactions cost), time to maturity and in/out of the money options on violation frequency. He argued that these effects may be proxy for friction existing in the markets which cause the violations. None of these effect has much explanatory power in accounting for the observed arbitrage opportunities. The largest coefficient of determination found was from the effect of stock price range (adjusted \( R^2 = 28.8\% \)), which highlight the importance of transaction costs.20 His general conclusion was that “observed violations of the put-call parity theorem were not sufficiently large to suggest that there existed potential for investors facing normal transactions costs to generate economic profits.” (p. 65)

Gray (1989)

The purpose of the study by Gray was not to test the AOM market efficiency but test the effect of early exercise, dividends payout and capitalisation changes in the boundary conditions. Nonetheless, as the methodology used was to create a hedged portfolio to discover potential abnormal profit, it provides evidence on AOM market efficiency.21 No specific stock option series was identified but rather stock and option prices

20 Since brokerage and stamp duties are positively related to share value and are a significant portion of the transaction costs, the effect of transaction costs are also determined by effect of share prices.
21 The hedges are constructed and defined in a similar method by Klemkosky and Resnick (1979).
were selected on the basis that they are traded within the same day with last sales price between the closing bid/ask spread and that all the securities are listed on the Sydney Stock Exchange. The period covered was from June 84 to May 86. For each of these option series, both long and short hedge portfolios were formed using similar methodology to Klemkosky and Resnick (1979). Market efficiency is supported when an insignificant number of long or short hedge earned abnormal profits. Out of a total number of 633 long and short hedges formed, only 67 (69) short (long) hedges were ex-ante profitable after cost and 67 (90) short (long) hedges were ex-post profitable after cost: a result which supports market efficiency.


The other direct test of market efficiency using the parity model was by Taylor. Taylor's data consisted of BHP options and Woodside options traded over the period Oct 82 to Oct 85. He found "a significant portion of put-call parity violations among AOM data for BHP and Woodside from 1982 to 1985 inclusive." (p. 215) but concluded that market inefficiency is not significant. This is due to the fact that transaction costs eliminate most violations and that the violations are concentrated in short-lived, over-priced put options. To take advantage of over-priced put options require a construction of a portfolio that involves illegal activity (short selling) and high contracting costs within the short time frame. Finally, it should be noted that Taylor reports that all of the violations occurred in the upper boundary, a result that directly conflicts with the findings of Loudon.
In an attempt to reconcile the two results, Brown and Easton (1991, 1992) duplicated the study using daily quote sheets data. They tested the BHP option series traded during the January 85 to September 85 period, a period of study common to both researchers. Their findings support Loudon as most of the violations occurred in the lower boundary. Further examinations of Taylor’s study shows that he made a few critical errors in his methodologies. These include the failure to correctly discount the exercise price, the inclusion of zero put price, the failure to ensure that data falls within bid ask spread, and the failure to ensure that securities are traded within the day. They therefore concluded that Taylor’s finding involving BHP option series should be disregarded. The other conclusion drawn from the analysis was that on a priori grounds, the data source in Loudon study (Register of Sales) cannot be concluded to be superior to the data in Taylor study (Australian Financial Review). This was due to the fact that the recorded option prices in the Register of Sales do not necessarily represent the time or sequence of the transaction but rather correspond only to the time when a trade was entered into the computer.

Comments and Summary

The early empirical work on the parity model by Stoll (1969) and Gould and Galai (1974) suffered from poor data source. The option price data observed were nominated option price and may not correspond to actual market option price. Furthermore, both studies limited the test to option series which had exercise prices equal to stock price. (At the money options.) Notwithstanding these limitations, Stoll’s finding of a significant positive relation between the relative call and put prices was enlightening. It was the one of the earlier empirical studies that confirmed the suspicion that there exists a relationship between the call and put price. The fact that the other regression coefficients do not correspond to the
predicted model was assumed away. However it could be hypothesised that this possible deviation was due to the fact that Stoll was using the standard put-call parity theorem to test America options. That is, he failed to take into account the possibility of early exercise of the options. In fact, in his reply to Merton's (1974) objection, he argued that the possibility of early exercise and the consequence for the parity were slight. The other possible reason for the difference in model-predicted coefficient and regression coefficient was that the market was indeed inefficient.

Gould and Galai (1974) in their test extended the parity model to take account of Merton's (1974) objection. Their major data still consisted of nominated price, though they were able to get market price from the diaries of a single stock option broker. This market price was used to gauge the accuracy and bias of the nominated price. They also rejected the use of regression to determine market efficiency. They concluded that the model did not seem to be-supported by the result of the analysis. (Even when using the market price and taking into account transaction costs). Transaction costs were found to be a significant factor in the efficiency of American OTC option markets. These costs should be less significant in the organised option market due to standardisation and the saving from having to match for buyer and seller. Thus, inefficiency in the OTC market is not surprising. There is a further possible reason that the market was found inefficient. Klemkosky and Resnick (1979) had argued successfully that the OTC market options were only partially dividend protected. Thus the Gould and Galai result could have been due to the omission of the dividend effects.

Klemkosky and Resnick (1979, 1980) used the most refined parity model. Their model takes into account the possibility of early exercise and dividend effect. Additionally, they do not limit their test to just at the money options. Their data source was also of higher quality as it had the times of trades and prices reported were market determined. These allowed them to l-gl the arbitrage strategy to find
out whether ex ante analysis of the parity yields abnormal profits. Though most of the hedged portfolios showed no exploitable profits, the trading strategy triggered by signals that indicated ex post profit exceeding $40 still earned an average of $58 per hedge. Transaction costs were unable to eliminate this profit. Thus the market showed some sign of inefficiency even though these abnormal profits are rapidly wiped out by subsequent price adjustment: a result that is consistent with previous tests of market efficiency using other methodology.

Following closely on the heels of the Klemkosky and Resnick (1980) studies, Phillip and Smith (1980) demonstrated the importance of implicit transaction costs such as bid/ask spread. Though most of the researchers agreed that transaction costs were important, they only concentrated on explicit transaction costs such as commission, cost of floor trading and clearing fees. Phillip and Smiths demonstrated that the implicit cost of bid ask spread required for the execution to exploit the abnormal profit was $50. This, coupled with the explicit costs, would have rendered the abnormal profit unexploitable. In fact, they show that the bid/ask spread will wipe out all previous reported abnormal profits found in the options market. Their article not only highlighted the importance of the bid/ask spread, it also showed that apparent inefficiency in the options market could be due to certain hidden costs.

It took two decades from the pioneering article of Stoll before the parity model was able to be used to test the efficiency of the AOM. The main problem was a lack of trading volume in put options. Loundon (1988) tested only a single option series (BHP), though it did cover more than half of the options market at that time.22 Furthermore, as noted in his introduction, the company was subject to takeover activity involving extensive option trading. The result of the analysis could therefore be firm and/or period specific. These points were conceded by Loudon.

22 The call (put) options accounted for 55% (72%) of total market volume and 74% (71%) in total market value for the period tested.
The surprising result of higher number of lower boundary violations than upper boundary violations could be due to the fact that there was selling or buying pressure on one of the securities which arose because of the takeover activity. A more diverse sample was chosen for the present study.

The other studies by Gray (1989) did not confine the test to a single company option series. Though the methodology was not to compute the parity boundaries and analyse the frequency of the violations, the frequency of the violations could be calculated by the number of profitable long and short hedges. A long hedge would be profitable if there is an upper boundary violation and conversely a short hedge would be profitable when a lower boundary violation occurred. These can be illustrated by noting that a long hedge was formed when call prices were relatively too high for put prices in the parity sense. To be consistent with Loudon's ex-post test, only Gray's ex-post results were used for comparison. Ex post results of 67 profitable short hedge and 90 profitable long hedge indicated that there were more lower boundary violations than upper boundary violations - which supports Loudon's finding.

The result of Taylor's (1990) study does not support the finding of more lower boundary violations than upper boundary violations. But as there are serious doubts raised by Brown and Easton (1991, 1992), no inference was drawn from this study.

A summary of the empirical research on the parity model to test market efficiency is presented in Table 4.

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23 Arbitrage of a breach in upper boundary condition requires the construction of a long hedge while lower boundary condition requires construction of short hedge.
Table 4
Summary of previous studies of put-call parity relation

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<td>As above</td>
<td>As above</td>
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CHAPTER 3
RESEARCH METHODOLOGY

Research Design

Using continuous discounting, the put-call parity theorem for American options over dividend paying stocks specified the following boundary conditions:

\[ C - S + K + De^{-RT} \geq P \quad \text{(5)} \]
\[ C - S + Ke^{-RT} \leq P \quad \text{(6)} \]

The upper boundary condition, equation (5), specifies that the put price should be lower than the left hand side expression of \( C - S + K + De^{-RT} \), and the lower boundary condition, equation (6), specifies that the put price should be greater than the left hand side expression of \( C - S + Ke^{-RT} \). If there is a boundary condition violation then there is potential arbitrage opportunity which is inconsistent with an efficient market. An upper boundary violation is thus defined when \( C - S + K + De^{-RT} \leq P \) and the upper violation size will be equal to \( C - S + K + De^{-RT} - P \). Similarly, a lower boundary violation is defined when \( C - S + Ke^{-RT} \geq P \) with lower violation size calculated as \( C - S + Ke^{-RT} - P \).

The research design is to gather data on equivalent call and put options. That is, put and call that relate to the same underlying stock and have same exercise price and time to maturity. These set of data are than used to compute the expression in (5) and (6) to see whether the boundary conditions hold in the AOM.
Data Source

The Australian Stock Exchange Journal publishes monthly trading statistics of all the options series traded in the AOM. For the period Jan 1991 to Dec 1991, it was observed that certain put options series were not traded at all or had very low trading volume. After careful analysis of the trading summary, it was decided to select the following option series for the test: BHP, CRA, WBC and WMC. These option series consistently have put monthly trading volumes of above 5,000 contracts. The four option series together accounted for approximately half the total trading volume for call and put contracts and also represented more than half the total market value of call and put contracts traded in the AOM. Figure 1 shows the breakdown in market share of AOM.

![Figure 1 (Share of Market)](image)

The four options series also represented a good mix of companies in Australia. Two of the companies are classified as industrial stocks (BHP and WBC) while the others represented the mining and resource sector (CRA and WMC). Possible company and sectoral specific effects can thus be examined in this study. Though the put-call parity theorem does not distinguish between companies or sectors, the different features in the companies or sectors could still have an effect on the frequency of observed violations. For example, certain firms or sectors may be

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27 The only exception are CRA June put monthly trading volume (4,879 contracts) and WBC September monthly trading volume (2,674 contracts).

28 In 1991, the four option series accounted for 42% (58%) of the number of call (put) contracts in AOM and 58% (65%) of the total market value of call (put) contracts in AOM.
less actively traded than other. Given that if a firm or sector has less trading interest relative to other firm or sector, arbitrage opportunities would be left undetected for a longer period. Thus it is expected that the less actively traded stocks will have more violations than the more actively traded stocks.\textsuperscript{26}

Due to the prohibitively high costs of obtaining data direct from the AOM, an alternative data source had to be found.\textsuperscript{27} The source chosen was the \textit{Australian Financial Review}'s daily price list for options and stocks. The published options' data in \textit{Australian Financial Review} are actually taken from the Daily Quote Sheet. Brown and Easton (1992) argued that on \textit{a priori} grounds, the quality of using Daily Quote Sheet as data source is as good as the so-called "transaction data" in Register of Sales. This is because both data sources could generate non-synchronous data that can cause significant error in a test of the put-call parity theorem. As noted by Loudon (1988), the price relation of the three assets as specified by the put-call parity theorem is only appropriate when they are based on the same information set. For puts and calls, the most important information set in determining price level is the price of the underlying share. Only when the prices of put and call are determined using the same traded share price level will there exist a put-call parity relation. In another words, the prices of the three assets must be observed at the same time or else there will not be a put-call parity relation.

Though the Register of Sales has a "transaction time" listed in the records, the time stamped are actually the times when the data are entered into the computer and not the time of transaction. It is therefore conceivable that puts traded hours apart from calls could be incorrectly matched in the analysis, simply because the trading data are entered into the computer at the same time. Similarly, if closing

\textsuperscript{26} The idea of investigating possible company and sector specific effects are drawn from Loudon's (1988, p.65) conclusion.

\textsuperscript{27} The Register of Sales record used in Loudon's study cost $90 per company per month while the Daily Quote Sheet mentioned in Brown and Easton (1992) and Taylor's (1989) article costs $2,000 for a year subscription. (Cost information supplied by the Australian Stock Exchange Ltd in Perth)
price are used, non synchronous price observation is conceivable given that the closing trades could be recorded at different time. For example, one of the assets (say the put) could have been traded in the early half of the trading day but not thereafter, while the other asset (say the call) was last traded at the end of the trading day. It would then be incorrect to use the closing prices of these two assets for the analysis since the two assets would be priced according to share prices at the different times.\cite{footnote28}

In order to reduce the problem of non-synchronous data, the following data filtering rules were used:\cite{footnote29}

(i) The closing price of the put is recorded only when it has non zero trading volume and non-zero closing price. Additionally, only a closing put price which falls within the bid/ask spread is used for the analysis.

(ii) The closing price of the corresponding call, (that is the call that has the same exercise price, maturity and underlying stock as the put) is also recorded only when it satisfies similar conditions of non-zero trading volume and non zero closing price falling within the bid/ask spread.

(iii) A check is made that the underlying stock is traded on the day in question and that the closing share price falls within the bid/ask spread.

(iv) Only data that satisfies these three conditions are used for the analysis.

By ensuring that all assets were traded on the day, the gross form of inter-day non-synchronous price observations is eliminated. That is, the mismatch of puts with calls or stocks that were in fact traded on different days is eliminated. Use of prices that fall only within the bid-ask spread also further reduces temporal mismatch. It should be noted that the bid-ask spreads are re-established at the end of each day and the bid (ask) quote is the price at which registered traders or specialists stand

\footnote{28 For a more detail discussion on the difference between the two data sources see Brown and Easton (1991, p.9-10).}

\footnote{29 The data filtering rules are adapted from Brown and Easton (1992, p. 6)}
ready to buy/sell the asset.\textsuperscript{30} Assets that are only traded early in the day with no transaction thereafter could show up when the market at the end of the day re-establishes a new bid/ask spread. For example, the closing price of a put which was transacted early in the day at 10 cents based on a $2 underlying share price would no longer fall into the bid/ask spread if the share price had moved to a new level (say $3) by the end of the day. Given that the bid/ask spread is the price level that registered traders or specialists stand ready to transact, it is most likely that it is established using the latest information set.\textsuperscript{31} This bid/ask spread condition also has the effect of reducing the bid/ask cost documented in Phillips and Smith (1981) article. In particular, it would also ensure that an investor can buy or sell the assets at the closing price recorded. Finally, the elimination of zero priced assets is to account for the objection by Brown and Easton (1992, footnote 10). They argued that put-call parity involves an arbitrage test and thus assets should not have a zero price because profits can be obtained simply by acquiring maximum quantities of these assets if they exist.

\textbf{Risk Free rate}

To arbitrage any put-call parity violation, the arbitrageur must be able to borrow or lend at the risk free rate. In addition the rate must be locked in, otherwise the portfolio profit will not be risk free. This would mean that the risk free rate used for the discounting factor must be for the period to the option's maturity. For example, to arbitrage a mis-priced pair of put and call option series with maturity of 90 days requires that the arbitrageur be able to borrow or lend at the 90 days risk free rate. A daily risk free rate is inappropriate as the rate may fluctuate between days and

\textsuperscript{30} Registered traders are the market makers in option market while their counterparts in stock market are the specialist.

\textsuperscript{31} I am grateful to Professor Brown of Monash for pointing out the advantage of using bid/ask spreads as a mean of reducing non-synchronous data.
the arbitrageur will not be able to lock in his position, say to cover the possible dividend payout, for a risk free profit. Unfortunately, it is not possible to get the risk free rate or its proxy to cover all the options' maturity periods.\textsuperscript{32}

The closest proxy for the risk free rate is the Treasury note rate. As noted in all Australian put-call parity articles, the infrequent trading of the Treasury note results in there being no rates available for numerous days. Thus, the study will only use the daily published Authorised Dealers Bank Bill (AD) rate in the \textit{Australian Financial Review} given that this rate is more readily available. The AD rates were reported for maturities of 30, 90 and 180 days. Depending on the maturities of the options the rate is chosen so as to be as close as possible to the option's maturity.\textsuperscript{33} The rates are than adjusted to reflect the maturity length of the options. The Australian Merchant Bankers Bill (AMBA) rates will also be used to examine the impact of using different discounting rates.\textsuperscript{34}

**Sample Period Study**

In an attempt to reduce the number of variables in the test and the measurement error of variables, it was decided to limit the period of test to include only periods where the stocks do not pay dividends. This has the effect of reducing the upper boundary condition to only $C - S + K > P$. The added advantage is that no risk free rates are used in the test of upper boundary condition and thus the result is robust

\begin{itemize}
\item[$\textsuperscript{32}$] The importance of getting the risk free rate to correspond with the maturity of the options was again highlighted to me by Brown.
\item[$\textsuperscript{33}$] In particular, options maturity of 0-60 days used 30 days AD rate as the discounting rate, 61-120 days used 90 days AD rate while options with maturity greater than 120 days used 180 days AD rate.
\item[$\textsuperscript{34}$] It should be noted that the Treasury bill rate is usually 0.5% less than the AD rate which is 0.5% less than the AMBA rate. In addition, all previous put-call parity articles found that the result of the test are insensitive to the rate used.
\end{itemize}
to the effect of using different discounting method (discrete and continuous) and different risk free estimate (T-note, AD and AMBA rates).

The sample to be studied is thus limited to option series that were traded and which matured prior to the ex-dividend dates of the underlying stocks. The Australian Stock Exchange Journal is used to obtain the ex-dividend dates of the stocks. For the BHP option series, the observed price data consist of options that were traded after 13/06/91 and matured prior to 4/11/91. The first date corresponds to the first ex-dividend date while the second corresponds to the next dividend payment ex-dividend date. Thus within this period of study no dividend is involved. Similarly, the sample period for CRA is 12/04/91 to 13/10/91, WBC 6/06/91 to 3/01/92 and for WMC 28/03/91 to 7/10/91.

**Hypothesis Tested**

Given that in an efficient market, there should not be any significant number of put-call parity violations for arbitrage opportunities, the first major testable hypothesis is as follows:

\[ H_1 : \text{There will be an insignificant number of upper and lower boundary violations after netting transaction costs. (in an efficient market)} \]

Loudon (1988, p. 56-57) in his analysis argued that on a theoretical ground, upper boundary condition should be more restrictive than lower boundary condition. This is because of stock short selling restrictions and dividend uncertainty in the upper boundary condition. Thus, one would expect to observe more upper boundary violations than lower boundary violations. Given that for the period covered in this study short selling of stock is permitted and that the sample specifically exclude dividends, the upper and lower boundary condition would thus be expected to be
equally restrictive. Thus, it is hypothesised that there should not be any significant difference in the frequency of upper and lower boundary violations and violation sizes.

\[ H_{2.1} : \text{There is no significant difference in the frequency of observed upper boundary violations and lower boundary violations.} \]

\[ H_{2.2} : \text{There is no significant difference in the observed upper boundary violation size and lower boundary parity violation size.} \]

Since put-call parity does not distinguish among firms or sectors, there should not be any significant difference in the number of boundary violations. Though it should be noted that the significant test of difference in violation size among firms are not conducted. This is because after the data filtering rule, the data set for each individual firms will have different mixes of exercise price and time to maturity. Thus, the violation size will be significantly different given that the violation size is calculated using exercise price and time to maturity.\(^{35}\) The third hypothesis tested is thus:

\[ H_3 : \text{There is no significant difference in the frequency of boundary violations among companies and sectors.} \]

Recall that only lower boundary condition of the put-call parity requires risk free borrowing. Drawing from Loudon's (1988) argument, the effect of Institutional restrictions on the required risk free borrowing will be more pronounced on longer term data series than on shorter term ones, thus the next hypothesis to be tested is:

\[ H_4 : \text{The frequency of lower boundary violations will be greater for options with longer terms to maturity.} \]

\(^{35}\) I am again indebted to Professor Brown for pointing out that the violation size among firm will differ significantly.
Again following from Loudon's (1988) article, it is hypothesised that since in the AOM there is more active trading of options which are "in the money" than of those which are "out the money", the violation on "in the money" options should be detected and arbitrated away more often than in the case of "out the money" options. Essentially, a lack of trading interest in "out the money" options would allow large violations to go undetected for a longer period, with the effect that the number of violations in "out the money" options would be greater compared to "in the money" boundary violations.

H₅: The frequency of boundary violations will be greater for "in the money" options than "out the money" options.

Statistical Analytical Techniques

To determine whether significant difference existed between sets of variables, two statistical tests will be utilised. These are the chi-square test and t-test. Chi-square test is only applicable for nominal data that are independent while a t-test requires interval data for the calculation of significant difference. Given that the frequency of boundary violation are nominal data, chi-square test will be utilised to test hypotheses that concern significant difference between the violation rates. Similarly, given that the violation size and boundary conditions are stated in terms of dollars amount (interval data), t-test will be used in analysing the violation size and boundary conditions. The significant difference in the test is exhibited in the probability value, thus the lower the probability value the more significance is the difference between the tested variables. Since chi-square and t-test only report whether the tested variables are significantly related but not how strong is the

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36 This section draws heavily from materials found in Levin's (1987) Statistics for Management book.
relation, a Spearman rank correlation test was also used in testing the strength of
the relation. Spearman rank correlation value range from +1 (strong positive
relation) to -1 (strong negative position). The Spearman rank correlation test is
used only when the data can be ranked and since the only variables in this study
that can be ranked is the time to maturity, this test is utilised in testing the strength
of the relation between time to maturity and the observed violation rates in
hypothesis 4. Finally the confidence level of the test is set at 95% or 5%
significance level. That is, the chance of rejecting a null hypothesis when it is true
(type I error) is 5%.

Advantages and disadvantages of testing the put-call parity
condition as a means of examining market efficiency

Before leaving the discussion on research design, the relative merits and
drawbacks of using the parity relation for testing the efficiency of the AOM requires
comment.

Advantages of using put-call parity in test of market efficiency

**Joint Test Hypothesis**

At the risk of sounding repetitive, the main advantage of using the put-call
parity condition as a test of market efficiency is to overcome the problem of
a joint test hypothesis. If no pricing model is specified, any inefficiency
found cannot be attributed to model mis-specification. Thus the argument is
that the put-call parity allows a direct test of market efficiency. Put-call parity
has the added advantage of minimising assumptions. There is no
specification of what investors' attitudes to risk are or about the process
generating asset returns. To ensure that any arbitrage profit will be totally eliminated in an efficient market the only assumption is that investors prefer more wealth to less and that tradings are frictionless. Though as noted by Loudon (1988, p. 54), trade to exploit arbitrage opportunities require perfect market and thus he argues that put-call parity analyses are not independent of institutional structures.

**Variables are observable**

Another advantage of using the put-call parity theorem is that most of the variables in the parity model are directly observable. The possible exception is the risk free rate but all models that require risk free discounting of a future value will also encounter this problem. Ignoring the inevitable problem of estimating the risk free rate, the put-call parity model does not require an estimate of the standard deviation of the stock price as does the B&S option pricing model. All the variables (call, put, exercise, stock price and maturity) are directly observable in the market and thus do not give rise to errors in measurement.

**Disadvantages of using put-call parity in test of market efficiency**

**Synchronisation of data**

As noted in earlier sections, one of the major problems in put-call parity analysis is to ensure that the prices observed are synchronised. If the data are non-synchronised, then it is erroneous to classify any violation found as violation of the put-call parity condition with resultant arbitrage opportunities. The data filtering rule used in this study will eliminate the
gross form daily mismatch of the three assets but within the day there is still scope for temporal mismatch. That is, it is possible that options are matched with stocks which are traded hours apart or vice versa. Nonetheless, as noted by Gray (1989, p.153) the non-synchronous data is not expected to present systematic bias over the sample.

Interestingly, Loudon's (1988) analysis found that the impact of price non-simultaneity on the frequency and size of violations was insignificant. He did, caution, though that the result could be due to possible stock price stability, which reduces the impact of matching calls and puts at different stock price levels, rather than to insignificant impact of non simultaneity of price observation.

**Ex-post and boundary condition test**

The other major problem in this study is that it is an ex post test. Galal (1978, p. 194) argues that ex post tests based on boundary condition can only conclude whether the relevant markets are synchronised or whether they are in continuous equilibrium. The results of such tests cannot be used to draw conclusions on the efficiency of the market. To exploit ex post arbitrage opportunities the asset prices must remain unchanged for the arbitrageur to set up the hedge portfolio. Therefore, it is conceded that a more stringent test of market efficiency would be to study ex-ante violation and to see whether arbitrage opportunities persist ex post. Nonetheless, as noted in Brown and Easton (1992) the available data set are not based on actual times of trade. To get a long enough period of transaction timed data is difficult and costly.1 Thus, given the data limitation it would be difficult to

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1 When the Register of Sales data are inputed in a more frequent and shorter time period, the data input time will approach the actual transaction data. Alternatively, the researcher would have to sit in the market and record the observed assets price as soon as they are transacted.
conduct a true ex-ante analysis of the put-call parity but the evidence collected could be considered as preliminary results till better data are available.
CHAPTER 4
RESULTS AND ANALYSIS

Violations of Boundaries

Table 5 provides the summary statistics for the observed boundary violations using the continuous discounting method and Authorised Dealers Bank Bill rate as risk free proxy. The "number of violations" row shows the number of cases in the sample where the upper and lower boundary conditions are not satisfied. That is, for upper boundary condition a violation occurs when \( C - S + K < P \) and lower boundary violation occurs when \( C - S + Ke^{-RT} \geq P \). The upper violation size is the amount of left hand side expression \((C - S + K)\) exceed the put price and the lower violation size is the amount of put price exceeding the left hand side expression of \( C - S + Ke^{-RT} \). The "violation rate" is the frequency of violations occurring in the sample. The equation for upper (eq. 5) and lower (eq. 6) boundary conditions are again reproduced below:

\[
C - S + K \geq P \quad \text{(5)}
\]

\[
C - S + Ke^{-RT} \leq P \quad \text{(6)}
\]

Table 5
**Summary of Violations** (Continuous discounting factor and Authorised Dealers Bank Bill rate as risk free proxy)

<table>
<thead>
<tr>
<th></th>
<th>Upper Boundary</th>
<th>Lower Boundary</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of Observations</td>
<td>1164</td>
<td>1164</td>
</tr>
<tr>
<td>Number of Violations</td>
<td>74</td>
<td>214</td>
</tr>
<tr>
<td>Mean violation size ($)</td>
<td>0.0314</td>
<td>0.0223</td>
</tr>
<tr>
<td>Standard Deviation ($)</td>
<td>0.0267</td>
<td>0.0013</td>
</tr>
<tr>
<td>Maximum violation size ($)</td>
<td>0.1300</td>
<td>0.1017</td>
</tr>
<tr>
<td>Minimum violation size ($)</td>
<td>0.0050</td>
<td>0.000033</td>
</tr>
<tr>
<td>Violation Rate</td>
<td>6%</td>
<td>18%</td>
</tr>
</tbody>
</table>

41 Given that the sample in this current study excludes dividends, the dividend term is dropped in the upper boundary condition, equation (5).
Given that only the lower boundary condition uses the risk free rate for discounting the exercise price, the impact of using different discounting methods and different risk free rate estimates will only affect the lower boundary violations. This is shown in Table 6. A comparison of Table 5 and Table 6 reveals that the effect of using different discounting methods and risk free rate estimates is minimal. The lower violation rate ranges from 16% to 18% and the mean violation size ranges from $0.0221 to $0.0223 depending on the discounting factor and risk free estimate. Given that the violation frequency and violation size varied only slightly, the following analysis will only use continuous discounting with the Authorised Dealers rate as the risk free proxy.

The results for the risk free proxy (AD v AMBA rate), supports previous studies where the use of different risk free proxies were found not to have any significant impact on put-call parity analysis. However, it should be noted that it is still important to use the risk free security with maturity closest to the maturity of the parity portfolio. The result only confirmed the empirical facts that the use of different available risk free proxies will not affect the result of put-call parity analysis.

Table 6

| Effect of different discounting methods and risk free estimates on the lower boundary |
|-----------------------------------------|-----------------|-----------------|-----------------|-----------------|
|                                      | A D Rates       | AMBA Rates      |                 |                 |
| Number of Observations               | Continuous      | Continuous      | Discrete        | Discrete        |
|                                       | C-S+Ke^{-T}     | C-S+Ke^{-T}     | C-S+K/(1+r)^T   | C-S+K/(1+r)^T   |
| Number of Violations                 | 1164            | 1164            | 1164            | 1164            |
| Mean violation size ($)              | 0.0223          | 0.0224          | 0.0221          | 0.0224          |
| Standard Deviation ($)               | 0.0013          | 0.0013          | 0.0183          | 0.0184          |
| Maximum violation size ($)           | 0.1017          | 0.1018          | 0.1002          | 0.1003          |
| Minimum violation size ($)           | 0.000033        | 0.000089        | 0.00018         | 0.0001          |
| Violation Rate                       | 18%             | 17%             | 16%             | 16%             |

42 See Loundon (1988, Table 2), Taylor (1989, footnote 10) and Brown and Easton (1992, footnote 8).
Market Efficiency (Hypothesis 1)

Out of the total number of 1164 observations, there were 74 cases of upper boundary violations and 214 cases of lower boundary violations. That is, only 74 cases of the data observed reported findings of upper boundary violations (C - S + K < P) while 214 cases reported lower boundary violations (C - S + Ke^{-TT} > P). These translate to an upper violation rates of 6% and lower violation rates of 18%. The mean violation size (arbitrage profitability) was $0.0314 and $0.0223 for upper and lower boundary violations respectively. Using Loudon's (1988) estimate of typical transaction costs involved in arbitraging a put-call parity violation, the transaction costs would range from $0.63 to $0.21, depending on the option series being arbitraged. (See Appendix A for calculation of transaction costs.) Given that the maximum violation sizes for upper and lower boundary conditions were $0.13 and $0.1017, none of the violations are profitable enough for arbitraging a breach in the put-call parity relation. The only traders that might reap an economic profit from trading in parity violations are traders who can escape brokerage costs. Nonetheless, if implicit costs such as bid-ask spread are accounted for, even they are unable to profit from a put-call parity violation. Note though that transaction costs can only explain why arbitrage opportunities are not exploited but it cannot explain

43 The preliminary analysis of upper boundary violation shows 106 cases of upper boundary violation with a violation rate of 9% but a closer examination reveals that there were 32 cases where the left hand side expression (C-S+K) yield negative or zero amounts. Given Brown and Easton's objection that put call parity are an arbitrage test and as such should not have any zero or negative priced security or portfolio, these cases are eliminated for the analysis. No zero or negative priced portfolio was found in the analysis of the lower boundary condition.

44 Economic profit as defined by Jensen (1978).

45 Even without invoking implicit transaction costs, the number of traders who can escape both option and stock brokerage fees will be minimum. This is because they must be exchange members of both the option and stock market in order to escape the total brokerage fees.
why arbitrage opportunities exist.\textsuperscript{46} Nonetheless, Taylor (1990, p. 211) argued that unexploitable arbitrage opportunities are consistent with an efficient market. 

To test the significance of the put-call boundary conditions, a simple paired t-test was conducted using the entire sample. The mean of the left hand side expression \((C-S+K)\) of equation (5) was compared with the mean put price \((P)\) for the upper boundary condition. The mean put price was in turn tested against the mean of the left hand side expression \((C-S+Ke^{-IT})\) of equation (6) for the lower boundary condition.

For the upper boundary condition, eq. (5), the mean left hand side expression \((M=0.3689)\) was found to be significantly greater than the mean put price \((M=0.2587)\), \(t=34.5128, p < .001\). The mean put price was in turn significantly greater than the mean left hand side expression \((M=0.2149)\) of the lower boundary condition, eq (6), \(t = 27.4921, p < .001\). The t-test thus support the hypothesis that the inequalities of the boundary conditions. The low frequency of violations being observed and given that none of the trade in parity violation are profitable net of transaction costs also attest to the efficiency of AOM in the time period of the study.

Upper and lower boundary conditions (Hypothesis 2)

From table 5, it can be seen that the rate of violation of the upper boundary condition (6%) is much lower compared to the lower boundary violation rate of 18%. The difference between the average upper violation and lower violation sizes is significant, \(t = 3.18, p<.002\). The result is consistent with Loundon (1988), Gray (1989) and

\textsuperscript{46} See Loundon (1988, p. 61, footnote 9) and Taylor (1990, p. 211)
Brown and Easton (1992) findings that there is more lower boundary violations than upper boundary violations.

Though the results confirmed previous studies that the lower boundary is violated more than the upper boundary, the results are still puzzling. Loudon (1988) argues that on theoretical grounds the upper boundary condition should be more restrictive than the lower boundary condition because of short selling restrictions and dividend uncertainty. That is, restrictions on the short selling required for arbitraging an upper boundary violation, would ensure that there are more upper boundary violations than lower boundary violations. Similarly, given that the dividend payout in the upper boundary is uncertain, it would again be expected that within a sample data there would be more upper boundary violations than lower boundary violations. Given that in this study, short selling of stocks is permissible in the sample period and that dividends are excluded from the study, the effect is that the upper boundary conditions are no longer as restrictive relative to the lower boundary. Thus theoretically we would expect in this study, the difference in violation rates and violation sizes between upper and lower boundary to be insignificant. This is not supported by the result of the analysis and thus hypothesis 2.1 and hypothesis 2.2 are rejected.

However, it should be noted that the mean size of violation of the upper boundary is now significantly greater than that in respect to the lower boundary. This is in contrast to Loudon’s study where he found a significantly higher mean violation size for the lower boundary than the upper boundary. Additionally, the lower violation rate of 18% is also lower than Loudon’s reported lower violation rate of 38.5%. Furthermore, the maximum violation size of this study was only $0.13 (upper boundary violation size)
while Loudon reported a maximum violation size of $0.33. (lower boundary violation size) This could be due to the learning effect alluded by Loudon in his conclusion.

Effect of different firms and sectors (Hypothesis 3)

Since the put-call parity theorem does not distinguish between firms or sectors, it is therefore not expected that a significant difference should be found in violation rates among firms and sectors. Table 7 shows the breakdown in the parity analysis across the four firms. Among the four firms, the upper boundary violation rate ranged from 6% to 8% with mean violation size ranging from $0.0131 to $0.0335 while the lower boundary violation rate ranged from 15% to 25% with mean violation size ranging from $0.0168 to $0.0327.

Table 7

Breakdown of parity analysis over different firms and sectors

<table>
<thead>
<tr>
<th></th>
<th>Industrial Sector</th>
<th>Resource and Mining Sector</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Upper</td>
<td>Lower</td>
</tr>
<tr>
<td>No. of Observations</td>
<td>543</td>
<td>543</td>
</tr>
<tr>
<td>No. of Violations</td>
<td>33</td>
<td>82</td>
</tr>
<tr>
<td>Mean violation size</td>
<td>0.0335</td>
<td>0.0243</td>
</tr>
<tr>
<td>Standard Dev</td>
<td>0.0284</td>
<td>0.0180</td>
</tr>
<tr>
<td>Max. violation size</td>
<td>0.1300</td>
<td>0.0757</td>
</tr>
<tr>
<td>Min. violation size</td>
<td>0.0050</td>
<td>0.0001</td>
</tr>
<tr>
<td>Violation Rate</td>
<td>6%</td>
<td>15%</td>
</tr>
</tbody>
</table>
To test whether the difference in violation rates among the firms are significant, a chi-square test was conducted. This is shown in table 8. The $\chi^2$ statistics support the hypothesis that there is no significant difference in violation rates across the four firms for the upper boundary conditions but surprisingly, there is a significant difference in lower boundary violation rates across the four firms, $\chi^2 (3, N = 1164) = 12.839, p< .005$

<table>
<thead>
<tr>
<th></th>
<th>Upper Boundary</th>
<th></th>
<th>Lower Boundary</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Comply Violations</td>
<td>Comply Violations</td>
<td>Total</td>
<td></td>
</tr>
<tr>
<td>BHP</td>
<td>510</td>
<td>33</td>
<td>461</td>
<td>82</td>
</tr>
<tr>
<td>CRA</td>
<td>194</td>
<td>18</td>
<td>177</td>
<td>35</td>
</tr>
<tr>
<td>WBC</td>
<td>233</td>
<td>15</td>
<td>186</td>
<td>62</td>
</tr>
<tr>
<td>WMC</td>
<td>153</td>
<td>8</td>
<td>126</td>
<td>35</td>
</tr>
<tr>
<td>Total</td>
<td>1090</td>
<td>74</td>
<td>950</td>
<td>214</td>
</tr>
</tbody>
</table>

$\chi^2 = 2.253, P< .5216 \quad \chi^2 = 12.839, P< .005$

Given that the sample periods for the four firms do not coincide exactly, the significant difference in the lower boundary violation rates could be due to the different trading days. That is, it is hypothesised that there may be certain trading days where the market is more active than others and when the market is active, arbitrage opportunities will be detected more quickly. Compared to a less active trading day where arbitrage opportunities will not be detected for a longer period than an active trading day. The $\chi^2$ tests were conducted again using data observations restricted to trading period common to the four firms (13/06/91-7/10/91). Table 9 shows the parity status for the four firms during the common period.
The result for the $\chi^2$ test shows that there is still a significant difference in violation rates across the four firms, $\chi^2 (3, N = 769) = 10.7747, p < .01301$ Even though the significant level has dropped from $p < .005$ to $p < .01301$, the difference in trading days still cannot explain the observed significant difference in lower violation rates among the four firms.

The possibility of a low trading volume effect was put forward by Loudon (1988, p. 65). He argued that in a less than perfect market, options which have low trading volume will be expected to have a larger violation rate since arbitrage opportunities for the less traded options are likely to remain undetected for a longer period. Given that BHP has the highest trading activity in the stock and options market it is thus expected to have the lowest violation rates. Among the four firms, BHP indeed has the lowest violation rate for lower boundary conditions (15%). Nonetheless, when we look at CRA which has the lowest call and put trading volume among the sample four firms, it was found that it has the second lowest lower boundary violation rates (17%). Thus the evidence that the more actively traded firms have lower violation rates is mixed and inconclusive.
Examining across sectors, the combined upper violation rates for the "industrial" sector (BHP and WBC) and the "resource" sector (CRA and WMC) are 5% and 7% respectively, while the combined lower violation rates are 17% and 21% respectively. The result of the $\chi^2$ test supports the hypothesis that there is no significant difference in violation rates across sectors. See table 10.

Table 10
Parity status across sectors

<table>
<thead>
<tr>
<th></th>
<th>Upper Boundary</th>
<th>Lower Boundary</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Comply</td>
<td>Violations</td>
</tr>
<tr>
<td>Industrial</td>
<td>743</td>
<td>48</td>
</tr>
<tr>
<td>Resource</td>
<td>347</td>
<td>26</td>
</tr>
<tr>
<td>Total</td>
<td>1090</td>
<td>74</td>
</tr>
<tr>
<td>$\chi^2$</td>
<td>0.05335, p&lt;0.81734</td>
<td>$\chi^2$ =0.34660, p&lt;0.55605</td>
</tr>
</tbody>
</table>

Effect of time to maturity (Hypothesis 4)

Since discounting of the exercise price is only required in specifying the lower boundary (and not in specifying the upper), "time to maturity" will affect only the former boundary. As argued by Loudon (1988), the reason that the longer maturity options are expected to show a higher violation rate is that the risk free proxy is not a true risk free rate and any divergence between the rates will be more pronounced as time to maturity lengthens. He thus argued that the effect of time to maturity could be a proxy for institutional restrictions on risk free borrowing. The effect of time to maturity on the put-call parity relation is shown in table 11.

The $\chi^2$ statistics show that there is a significant association between the time to maturity and the observed violation rate while the Spearman rank correlation shows a
strong inverse relationship between the violation rate and the time to maturity.

Though the hypothesis predicts that the lowest violation rate and violation size should be in the longest time group (>120 days), the result shows that the second longest group has the lowest violation rates and violation size. A similar result was also found in Loudon's study.\(^{47}\)

Table 11

**Effect of time to maturity on the lower boundary**

<table>
<thead>
<tr>
<th>Time to Maturity (days)</th>
<th>Total Observations</th>
<th>No. of Violations</th>
<th>Violation Rate</th>
<th>Mean (S)</th>
<th>Std Dev. (S)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-30</td>
<td>385</td>
<td>104</td>
<td>27%</td>
<td>0.02387</td>
<td>0.02075</td>
</tr>
<tr>
<td>31-60</td>
<td>312</td>
<td>67</td>
<td>17%</td>
<td>0.02118</td>
<td>0.01743</td>
</tr>
<tr>
<td>61-90</td>
<td>249</td>
<td>29</td>
<td>8%</td>
<td>0.02165</td>
<td>0.01570</td>
</tr>
<tr>
<td>91-120</td>
<td>140</td>
<td>5</td>
<td>1%</td>
<td>0.00664</td>
<td>0.01363</td>
</tr>
<tr>
<td>120+</td>
<td>78</td>
<td>9</td>
<td>2%</td>
<td>0.02150</td>
<td>0.01629</td>
</tr>
</tbody>
</table>

\[ x^2 = 51.5, \ p < 0.001 \]

rank correlation = -0.9.

Effect of the option's being "In the money" (Hypothesis 5)

It was observed in the sample that the trading volume for calls that are "in the money" was significantly greater than that of calls that are "out of the money". Figure 2 gives the breakdown in trading volume for calls in terms of "In", "at" or "out of" the money category.

\(^{47}\) Though it should be noted that his time to maturity category is slightly different from this study.
Given that options with lower trading volume are expected to have potential arbitrage opportunities undetected for longer, it would thus be expected that calls that are "out of the money" would show significantly greater violation rate than "in the money" calls. Table 12 shows the parity analysis for "in" or "out of the money" calls. To be consistent with Loudon's study, the "at the money" calls are classified as "out of the money".

Table 12

<table>
<thead>
<tr>
<th>Category</th>
<th>Total Observations</th>
<th>No. of Violations</th>
<th>Violation Rate</th>
<th>Mean</th>
<th>Std Dev</th>
</tr>
</thead>
<tbody>
<tr>
<td>In</td>
<td>711</td>
<td>46</td>
<td>6.5%</td>
<td>0.1115</td>
<td>0.1102</td>
</tr>
<tr>
<td>Out</td>
<td>453</td>
<td>28</td>
<td>6.2%</td>
<td>0.1081</td>
<td>0.1089</td>
</tr>
</tbody>
</table>

\[ \chi^2 = 0.03875, p < 0.0439 \]

<table>
<thead>
<tr>
<th>Category</th>
<th>Total Observations</th>
<th>No. of Violations</th>
<th>Violation Rate</th>
<th>Mean</th>
<th>Std Dev</th>
</tr>
</thead>
<tbody>
<tr>
<td>In</td>
<td>711</td>
<td>113</td>
<td>15.9%</td>
<td>0.0448</td>
<td>0.0505</td>
</tr>
<tr>
<td>Out</td>
<td>453</td>
<td>101</td>
<td>22.3%</td>
<td>0.0423</td>
<td>0.600</td>
</tr>
</tbody>
</table>

\[ \chi^2 = 7.560, p < 0.006 \]
The lower boundary exhibits a significant relation between the observed violation rates and the category of "in" or "out" of the money calls while the upper boundary relationship is not significance. The violation rates for both the upper and lower violation are in the direction specified by the hypothesis. That is, the "out of the money" calls show a higher violation rate than do the "in the money" calls.

Loudon's (1988) study further partition the call into deep in and deep "out of the money". It is not clear what the objective of this exercise is, given that the low trading volume effect predicts only that "in the money" calls (which are more actively traded) should have a lower violation rates than "out of the money" calls. Since the degree of calls "in the money" is arbitrary, it is difficult to ascertain a level for identifying whether the deeper the call the more trading volume is observed. For example, within a data set a call that is classify as deep in when stock price exceed exercise price by 10c will definitely have more trading volume than a call classify as deep in with the cut-off point at 20c. That is because the 20c deep in calls now exclude the trading volume for the previous 10c "in the money" calls. If the cut-off point is set high enough there will not be any trade observed within the deep "in the money" calls category! Thus, the trading volumes allow one to observed whether AOM traders prefer "in" or "out of the money" calls but not be able to extend the observation to discover the category of deep "in the money" options, traders in AOM would prefer.

To further examine the significant relation found between "in" or "out" of the money calls and lower boundary condition, the four individual firms were tested in isolation. Table 13 shows the crosstabulation table for the violation rates. Only BHP show a significance relation between "in" or "out" of the money call category and the lower violation rate, $\chi^2 (1,N=545)=4.3256, p<.03754$. The other firms, CRA ($p<.8594$), WBC ($p<.3749$), and WMC ($p<.1129$) all show insignificant relation between in or out call category and the lower violation rates. Nonetheless, the lower violation rates for
for "in the money" calls were found to be always smaller than "out of the money", except for WBC which had lower violation rates being slightly smaller in "out of the money" options than "in the money" options. Thus the evidence support the hypothesis that the less actively traded "out of the money" calls have more violations than the more actively traded "in the money" calls.

Table 13

Lower boundary parity status for "in" or "out" of the money calls among the four firms.

<table>
<thead>
<tr>
<th></th>
<th>BHP</th>
<th>CRA</th>
<th>WBC</th>
<th>WMC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Category</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Comply</td>
<td>Violations</td>
<td>Comply</td>
<td>Violations</td>
</tr>
<tr>
<td>In</td>
<td>85.3%</td>
<td>14.7%</td>
<td>83.9%</td>
<td>16.1%</td>
</tr>
<tr>
<td>Out</td>
<td>80.5%</td>
<td>19.5%</td>
<td>83.0%</td>
<td>17.0%</td>
</tr>
<tr>
<td>$\chi^2$</td>
<td>=4.3257, $\chi^2$</td>
<td>=0.0313, $\chi^2$</td>
<td>=0.7873, $\chi^2$</td>
<td>=2.5132,</td>
</tr>
<tr>
<td>p</td>
<td>&lt;.03754</td>
<td>p&lt;.8594</td>
<td>p&lt;.3749</td>
<td>p&lt;.1129</td>
</tr>
</tbody>
</table>

Conclusion

The primary objective of the study is to gather evidence on the efficiency of the Australian Options Market. The results support the finding that AOM is highly efficient in the period study. Breaches of the put-call parity boundaries (upper and lower) were found to be infrequent. Even when the boundary conditions are violated, the arbitrage opportunities were not exploitable. This is because the transaction costs exceed the potential arbitrage profits. Though transaction costs cannot explain the existence of arbitrage opportunities, the fact that arbitrage opportunities are unexploitable is consistent with notion of market efficiency.
The infrequent violations of put-call parity boundaries also indicate that pricing relation between puts and calls are maintained in the Australian market. Thus the empirical evidence in Australia supports the pricing relation of the put-call parity model. Lower boundary violations occur more often than upper boundary violations. This is despite the fact that removal of institutional restriction on short sale of stocks and dividends uncertainty should make both boundary conditions to be equally restrictive. In addition, the lower boundary condition of put-call parity relation appears to be affected by companies specific effect, time to maturity effect and the effect of whether options is "in" or "out the money" effect. No such relation was found between the upper boundary condition and the various effects.
CHAPTER 5
SUMMARY AND CONCLUSION

Purpose of Study

The primary aim of this study was to investigate the market efficiency of the AOM. Though there were substantial numbers of previous studies conducted in exploring the market efficiency of the AOM, they were studied under different institutional structure. The institutional structure changes include introduction of spot options and removal of restrictions on short sale of stocks.

The second objective of the study was to gather empirical evidence on the put-call parity theorem. Specifically, the effects of time to maturity and options being "in the money" on put-call parity relation were examined. Additionally, this study also explored the company and sector effect which was only reported in Taylor’s (1990) study. Though as noted previously, there is serious doubts raise on his methodologies and therefore his results are questionable.

Method of Study

Call, put and stock prices were collected from the National Market sections of the Australian Financial Review. Risk free rate was estimated using Authorised Dealers Bank Bill rate and Australian Merchant Bankers Bill rate which was also available in the Australian Financial Review. This data were then enter into the put-call parity boundary equations, reproduced below.

\[ C - S + K \geq P \] \hspace{1cm} (5)

\[ C - S + Ke^{-rT} \leq P \] \hspace{1cm} (6)
A violation is defined when the parity boundary conditions were not satisfied. These violations represent arbitrage opportunities. Since in an efficient market there should not be any arbitrage opportunities, violation rate is thus an indication of the market efficiency in the AOM. Additionally, various effects on put-call parity relation were also examined. The results of the analysis are summarised below.

Summary of Results

Market Efficiency (Hypothesis 1)

The first test involved calculating the violation rates and violation size. Given that in an efficient market there should not be any significant number of put-call parity violations, the first hypothesis tested (stated in the alternate form) is:

\[ H_1: \text{There will be an insignificant number of upper and lower boundary parity violations after netting transaction cost in an efficient market.} \]

Of the 1164 observations, 74 cases of upper boundary violations and 214 cases of lower boundary violations were observed. These translate to an upper violation rate of 6% and lower violation rate of 18%. None of the breaches in parity violation are profitable for arbitrage when transaction costs are accounted for. In addition, the t-test results also support the put-call parity boundary equations. That is, there is a significant difference in the mean of the left hand side expression from the mean of the right hand side expression for both boundary equations. Thus the evidence of the analysis support hypothesis 1 and attest to the efficiency of the AOM.
Upper and lower boundary conditions (Hypothesis 2)

Loudon (1988) in his analysis argued that restriction on short sale of stock and dividend uncertainty implied that upper boundary condition should be more restrictive than the lower boundary condition. Given that the short selling of stock is permitted in the period covered in this study and that the sample specifically exclude dividends, the upper and lower boundary condition would be expected to be equally restrictive. Thus it is expected that an insignificant difference in upper and lower violation rates and violation size would be observed.

\[ H_{2,1} \] : There is no significant difference in the frequency of observed upper boundary parity violations and lower boundary parity violations.

\[ H_{2,2} \] : There is no significant difference in the observed upper boundary violation size and lower boundary parity violation size.

The results do not support the hypothesis that there is no significant difference in upper and lower boundary violation rates and violation size. Lower boundary violations were observed more often than upper boundary violations. The result in the test supported Loudon (1988), Gray (1939) and Brown and Easton (1992) findings. However, the upper violation size was greater than the lower violation size which is inconsistent with previous studies. Results of the present study also reported a smaller violation size compared to findings of previous studies which could be possible learning effect occurring in AOM.
Effects of firms and sectors (Hypothesis 3)

Given that put-call parity does not distinguish amongst firms or sectors, there should not be any significant difference in the number of boundary violations observed across the four firms.

\[ H_3 : \text{There is no significant difference in the frequency of boundary violations among companies and sectors.} \]

No significant difference in the frequency of upper boundary violations were found among the four firms but the frequency of the observed lower boundary violations exhibit a significant difference among the firms. The evidence for effect of low trading volume to explain the significant difference is mixed. It correctly predicted that the most actively traded firm BHP would have the lowest violation rates but the least traded firm, CRA, has the second lowest lower violation rate which is inconsistent. Thus "low trading volume" effect appears not to be the cause of the significant relation found between violations rates and firms.

Effect of time to maturity (Hypothesis 4)

Given that the rate used in the put-call parity analysis is not true risk free rate, the effect of using a different rate should be more pronounced as time to maturity lengthens. This effect will only affect the lower boundary since discounting of the exercise price is only required in the lower boundary.
\( H_4 \): The frequency of lower boundary violations rate will be greater for options with longer terms to maturity.

The result shows there is a significant association between the frequency of observed violations and time to maturity. Generally, the shorter time to maturity options tend to exhibit a lower observed violation rate and violation size. Though surprisingly, the lowest violation rate and violation size was observed in the second longest time to maturity group.

**Effect of the option's being "in the money" (Hypothesis 5)**

By noting that "out of the money" options are relatively less traded than "in the money" options and that the effect of low trading would cause more violation to be undetected, the next hypothesis tested was:

\( H_5 \): The frequency of boundary violations will be greater for "in the money" options than "out of the money" options.

The result for upper boundary violation reports that there is slightly more violations in "in the money" options than "out of the money" options. This is inconsistent with the hypothesis, though the association between frequency of observed violations and "in", "out" of the money is not significant. The evidence for lower boundary violation supports the hypothesis that the less actively traded "out of the money" options will have more violations than "in the money" options. The relationship between frequency of observed violations and "in", "out" of the money was found to be significant. Looking at individual firm in isolation the result also supports the hypothesis that "out
of the money" options should have more violations than "in the money" options. Though it should be noted that only BHP options show a significant relation between frequency of observed violations and "in", "out" of the money options.

Conclusion

The findings of the analysis leads to the following conclusion:

i) The Australian Options Market was efficient in the period study.

ii) The difference in violation rates and violation sizes were significantly different between upper and lower boundaries. Despite the removal of institutional restrictions on short sale of stocks, lower boundary violation rate was still greater than upper boundary violation rate.

iii) There appears to be a significant relation between firms and frequency of observed lower boundary violations. "Low trading volume" effect fail to explain the significant difference in violation rates among the firms, though it did correctly predicted that the most actively traded firms will have the lowest violation rate.

iv) The effect of time to maturity, a proxy for institutional restriction on risk free borrowings, appear to have a significant effect on put-call parity relation.

v) "In the money" options have less lower boundary violations than "out the money" options. "Low trading volume" effect appear to be the causes for the difference in observed violation rates between the "in the money" options and "out the money" options.
Future Research Direction

Given that the sample period in this study only covered six months, a longer time period would aid in further understanding of the various effects on put-call parity relation. Further research should also be conducted to test why violations occur more often in lower boundary than upper boundary. Also given that the data use in this and other study are not true transaction data, there is always the possibility of non-synchronous data observation. The current data limitations also exclude the ability to conduct an ex ante test. Thus further ex ante tests using better data source would also be invaluable in testing the efficiency of the Australian Options Market.
Appendix A (Transaction costs)

Following Loudon's (1988) construction of an arbitrage trade for an underpriced put, the following transaction costs are calculated. The following transactions are required: puts contracts are bought, calls contract written and number of shares are bought initially which are later closed at the end of the arbitrage and funds must be borrowed. Thus ignoring cost of borrowing, the typical transaction costs for arbitraging the maximum lower violation size found in this study are:

**BHP transaction costs for arbitraging a $0.08 lower violation size**

<table>
<thead>
<tr>
<th>Positions</th>
<th>Brokerage</th>
<th>Stamp Duty</th>
<th>Exchange Fees</th>
</tr>
</thead>
<tbody>
<tr>
<td>Buy 100 puts @ $0.7 per share unit</td>
<td>1,400</td>
<td>21</td>
<td>120</td>
</tr>
<tr>
<td>Sell 100 puts @ $0.02 per share unit</td>
<td>40</td>
<td>0.6</td>
<td>120</td>
</tr>
<tr>
<td>Buy 100,000 shares @ $13.95 each</td>
<td>27,900</td>
<td>4,185</td>
<td></td>
</tr>
<tr>
<td>Sell 100,000 shares @ $14.95 each</td>
<td>28,900</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>58240</td>
<td>4206.6</td>
<td>240</td>
</tr>
<tr>
<td>Total Cost= $62,887, per unit = $0.63</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**CRA transaction costs for arbitraging a $0.10 lower violation size**

<table>
<thead>
<tr>
<th>Positions</th>
<th>Brokerage</th>
<th>Stamp Duty</th>
<th>Exchange Fees</th>
</tr>
</thead>
<tbody>
<tr>
<td>Buy 100 puts @ $0.035 per share unit</td>
<td>70</td>
<td>1.05</td>
<td>120</td>
</tr>
<tr>
<td>Sell 100 puts @ $0.02 per share unit</td>
<td>1,840</td>
<td>27.6</td>
<td>120</td>
</tr>
<tr>
<td>Buy 100,000 shares @ $12.75 each</td>
<td>25,500</td>
<td>3,825</td>
<td></td>
</tr>
<tr>
<td>Sell 100,000 shares @ $13.25 each</td>
<td>26,500</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>53,910</td>
<td>3,853.65</td>
<td>240</td>
</tr>
<tr>
<td>Total Cost= $58,004, per unit = $0.58</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

---

1 Prices are the actual observed stock, call and put price for the maximum lower violation size data. That is, BHP has the highest lower violation size of $0.08 and for this violation the corresponding stock, call and put prices are $13.95, $0.02 and $0.7 respectively. It is then assumed that stock price rise by $0.5 when the arbitrage portfolio are terminated.

2 Brokerage is at 2% of contract value. Though it should be noted that brokerage rates are negotiable and 2% are used as a indicative rates. Also note that option contracts value are per share unit, thus 100 puts will be equivalent to 1,000 share units.

3 Stamp Duty is charged on a rate of 30 (3c) per $100 of contract value for shares(options).

4 Stock Exchange Fees are levied using the following scale:

<table>
<thead>
<tr>
<th>No. of Option Contracts</th>
<th>$ per contract</th>
</tr>
</thead>
<tbody>
<tr>
<td>1-19</td>
<td>1.5</td>
</tr>
<tr>
<td>20-49</td>
<td>1.4</td>
</tr>
<tr>
<td>50-99</td>
<td>1.3</td>
</tr>
<tr>
<td>&gt;99</td>
<td>1.2</td>
</tr>
</tbody>
</table>
### WBC transaction costs for arbitraging a $0.09 lower violation size

<table>
<thead>
<tr>
<th>Positions</th>
<th>Brokerage</th>
<th>Stamp Duty</th>
<th>Exchange Fees</th>
</tr>
</thead>
<tbody>
<tr>
<td>Buy 100 puts @ $0.19 per share</td>
<td>380</td>
<td>5.7</td>
<td>120</td>
</tr>
<tr>
<td>unit</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sell 100 puts @ $0.05 per share</td>
<td>100</td>
<td>1.5</td>
<td>120</td>
</tr>
<tr>
<td>unit</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Buy 100,000 shares @ $4.51 each</td>
<td>9,020</td>
<td>1,353</td>
<td></td>
</tr>
<tr>
<td>Sell 100,000 shares @ $5.01 each</td>
<td>10,020</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>19,520</td>
<td>1,360.2</td>
<td>240</td>
</tr>
<tr>
<td><strong>Total Cost</strong>=$21,120, per unit = $0.21**</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### WMC transaction costs for arbitraging a $0.05 lower violation size

<table>
<thead>
<tr>
<th>Positions</th>
<th>Brokerage</th>
<th>Stamp Duty</th>
<th>Exchange Fees</th>
</tr>
</thead>
<tbody>
<tr>
<td>Buy 100 puts @ $0.04 per share</td>
<td>80</td>
<td>1.2</td>
<td>120</td>
</tr>
<tr>
<td>unit</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sell 100 puts @ $0.71 per share</td>
<td>1,420</td>
<td>21.3</td>
<td>120</td>
</tr>
<tr>
<td>unit</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Buy 100,000 shares @ $5.30 each</td>
<td>10,600</td>
<td>1,590</td>
<td></td>
</tr>
<tr>
<td>Sell 100,000 shares @ $5.80 each</td>
<td>11,600</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>23,700</td>
<td>1,612.5</td>
<td>240</td>
</tr>
<tr>
<td><strong>Total Cost</strong>=$25,553, per unit = $0.26**</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
References


