# IMPLIED ADJUSTED VOLATILITY FUNCTIONS: EMPIRICAL EVIDENCE USING AUSTRALIAN INDEX OPTIONS

BY

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# ABSTRACT

Volatility implied by an option pricing model is seen as the market participants' assessment of volatility. With the implied volatility as a significant aspect particularly in option valuation, this study examines the implied volatility smiles and term structures in the Australian Standard and Poor/Australian Stock Exchange (S&P/ASX) 200 index options over the course of 2001-2010, including the global financial crisis in the mid-2007 until the end of 2008. This study utilised the models of Leland (1985) and Leland (2007).The results show that the implied volatility rises significantly during the crisis period, which is more than the rate found before the crisis. Given the fact that the pricing biases of Leland option pricing models and the implied volatility structure of the option are related, secondly, this research adapts and modifies the models in Peña, Rubio and Serna (1999) and Engström (2002), in order to analyse whether the use of the implied adjusted volatility functions delivers an improvement in the option valuation accuracy of the index options. Both in- and out-of-sample resulted in approximately similar pricing error along the different Leland's models. This study employs 2-step process. Results indicate that different implied adjusted volatility functions best explain the index options in different period of intervals (pre-, during and post-crisis). This shows that it is tremendously important to identify the intervals beforehand in investigating the implied adjusted volatility function.

# خلاصة البحث


إن نموذج التسعيرة عن طريق الإختيار الحر ينظر إليه على أنه تقييم للمشاركين في عمليات السوق وتقّلب الأسعار. هذه دراسة تبحث بسمة وهيكل لتقلب ضمني في 200 خيارات فهرس من Australian Standard and Poor/Australian Stock Exchange (S&P/ASX) من 2001 إلى 2008 بوصف التقلّب الضمني كجانب مهم في تحديد القيمة والخيار. هذه دراسة تتضمن الأزمة المالية العالمية من أواسط عام 2007 إلى نهاية عام 2008. هذه دراسة استخدمت نموذجين من Leland (1985) و Leland (2007). أظهرت النتائج أن التقلّب الضمني يرتفع بشكل ملحوظ خلال فترة الأزمة الي أكثر من قبل الأزمة. هذه دراسة تتكيف وتتغير وفق نموذجين من Peña و Rubio و Serna (1999) و Engström (2002) نظراً لحقيقة أن التحيزات تسعير في نموذجين لتسعير الخيار ل-Leland تتعلق بهيكل الخيار للتقلّب الضمني، ذلك من أجل تحليل ما إذا كان وظائف التقلّب المعدل الضمني يحسن الضبط تقييم للخيار الفهرس. كان داخل وخارج عينتين نتجا من خطأ تسعير مماثلة تقريبًا على نماذج مختلفة. هذه دراسة استخدمت عملية الخطوتان. أشارت النتائج إلى أن وظائف التقلّب المعدل الضمني مختلفة، وتوضح أن خيار الفهرس في فترة الفاصلة مختلفة، أي مرحلة ما قبل الأزمة وخلالها ومرحلة ما بعدها. وهذا يدل على أنه من المهم جداً التعرف على فترات قبل التحقيق على الوظيفة التقلّب المعدل الضمني.

# APPROVAL PAGE

I certify that I have supervised and read this study and that in my opinion, it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a thesis for the degree of Master of Science in Computational and Theoretical Sciences.

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I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a thesis for the degree of Master of Science in Computational and Theoretical Sciences.

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Dean, Kulliyyah of Science

# DECLARATION

I hereby declare that this dissertation is the result of my own investigations, except where otherwise stated. I also declare that it has not been previously or concurrently submitted as a whole for any other degrees at IIUM or other institutions.

Hanani Farhah binti Harun

Signature ........................................................... Date .........................................

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Signature Date

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| | |
|---|---|
| BSM | Black-Scholes-Merton |
| DVF | Deterministic Volatility Function |
| ASX | Australian Stock Exchange |
| ITM | in-the-money |
| OTM | out-of-the-money |
| ATM | at-the-money |
| DITM | deep-in-the-money |
| DOTM | deep-out-of-the-money |
| PHLX | Philadelphia Stock Exchange |
| CBOE | Chicago Board Options Exchange |
| CRSP | Berkeley Options Data Base |
| LIFFE | London International Financial Futures and Options Index |
| GARCH | Generalized Autoregressive Conditional Heteroscedasticity |
| SV | stochastic volatility |
| StSE | Stockholm Stock Exchange |
| S&P | Standard & Poor |
| XJO | S&P/ASX 200 Index |
| XFL | S&P/ASX 50 Index |
| XPJ | S&P/ASX 200 Property Trusts Index |
| BAB | Bank Accepted Bill |
| LEPO | Low Exercise Price Option |
| ADF | Augmented-Dickey-Fuller |
| RMSE | Root mean square error |
| LS | Least Squares |
| NLS | Nonlinear Least Squares |
| OLS | Ordinary Least Squares |
| SSE | sum of square error |
| GLS | Generalized Least Squares |
| SD | standard deviation |
| ADF | Augmented Dickey-Fuller |

# CHAPTER ONE

# INTRODUCTION

## 1.1 BACKGROUND OF THE STUDY AND MOTIVATIONS

Investors view the ability to foresee volatility as something prominence. The risks-anticipation power of volatility assists investors in figuring the appropriate hedging strategies. Apart from that, the market estimate of volatility serves as the stock market vulnerability gauge or a risk measure for policy makers. Having to know the volatility of the market in advance aids the policy makers. The capital flow can be prevented from redirect away from the market if the situation is unfavourable to investors. Stock market volatility likewise is a vigorous variable in derivatives pricing. Consequently, volatility of an underlying asset is an essential element in making decision in financial market.

To date, academics or practitioners have developed a few different techniques in estimating volatility realising the vitality of knowing the risks beforehand. Among them is the implied volatility based on option pricing models. Implied volatility gives a value in which the theoretical value equals to the market price. A number of earlier literature documented that implied volatility based on an option pricing model was found to be informationally superior to historical volatility in forecasting future realised volatility (Szakmary, Ors, Kim & Davidson, 2003; Li & Yang, 2009; Jiang & Tian, 2005).

The model introduced by Black and Scholes (1973) and Merton (1973) rests on the assumptions of no arbitrage, pricing log-normality and frictionless trading. Therefore, the introduction of this Black-Scholes-Merton (hereafter, BSM) model in the 1970s has invited criticism. One of the criticisable pricing anomalies in this model is; if the conditions in financial market are accurately reflected by the model, then the implied volatility of the option on the same underlying asset should be constant or invariant of the strike price or time to maturity of the options. However, the implication of this assumption is not true. Most researchers have investigated that when time to maturity is fixed, the implied volatility is discovered to be systematically varied for diverse strike price and expiration periods. This is contrary to the implication of the BSM model. Thus, the inability of this model to handle the volatility smile or skew phenomenon has become the major flaw of the BSM model in pricing options.

Owing to the pitfalls of the BSM model in pricing options, the volatility implied from this model is unable to directly proxy the true expectation of future realized volatility (Shu & Zhang, 2003). Henceforth, a number of models have been developed to fill this void, such as the regression-based deterministic volatility function (DVF) model. The regression-based DVF model is an effective approach in valuing volatility and is extensively used as a benchmark (Christoffersen *et al*., 2009, Berkowitz, 2010).

Leland (1985) is among the first that improved the BSM model by developing a hedging strategy that incorporates an adjusted volatility. The volatility is adjusted with respect to the length of rebalance intervals, proportional transaction cost rate and the volatility of the underlying asset. Leland (1985) also claimed that by forcing the length of rebalance intervals to approach zero, zero hedging error can be achieved in the limit. Even though the idea is quite relevant, this model does not integrate the initial cost of trading into the assumptions. In response to the drawbacks of the original model, Leland (2007) provided two adjustments; namely Leland (2007) cash model and Leland (2007) stock model. In these models, he explicitly considered initial costs of trading into the assumptions that the initial portfolio is either consists of all cash or all stock position.

Despite the fact that BSM model has a major flaw, yet it is still acknowledged by many studies as a relevant option pricing model. Many other models are the extension of the BSM model. Many empirical studies use BSM model as a benchmark or as an interpolation tool in investigating the performance of various option pricing models (Figlewski, 2002; Christoffersen & Jacobs, 2004; An & Suo, 2009). The introduction of BSM model to the financial world has inspired numerous literature to examine the forecasting ability of implied volatility in time series framework (Chernov, 2001). A model which considers realistic transaction costs seems to be more suitable in handling option. It is hypothesised that using the Leland option pricing models which have both the almost identical framework to that of the BSM model and incorporate the stochastic nature of volatility in its model appears to be relevant in this study. This research employs the Leland (1985) model and its two variations in estimating implied volatility, namely *implied adjusted volatility*. It is hypothesised that the adjusted volatility implied from the different Leland option pricing models should be equal.

Implied adjusted volatility is a significant aspect particularly in option valuation. It is demonstrated in many literature that the implied (adjusted) volatility to be changing across option's moneyness[1] and time to maturity. Volatility surface is the consequential result of the blending[2] shifting (See Chapter 2). Even it is well-accepted by an overwhelming number of literature that volatility varies across moneyness and

[1] Moneyness is the measure of option being in-the-money.
[2] Blending shifting refers to the mixing effect of smile and term structure phenomena. Smile or smirk or skewness depicts the changing of volatility across moneyness. Term structure describes the changing of volatility across time to maturity.See Chapter 2 for details.

maturity, the real reasons behind that still remain blurred. It is claimed that the movements in the changes of smile in option prices are very much predictable (Goncalves & Guidolin, 2006; Wallmeier, 2012). This study firstly aims to investigate the implied adjusted volatility smile patterns in index (equity) options using the different Leland option pricing models. This research is conducted to identify any regularity in pattern in the implied volatility surfaces and to provide a better understanding of the phenomenon. In other words, this research is expected to give a brief idea on the degree of dependency between the implied adjusted volatility with the other parameters.

Peña, Rubio and Serna (1999) and Engström (2002) have developed possible specifications of the implied volatility functions and examined whether using these implied volatility functions can result to an enhancement to option valuation accuracy. Following Peña *et al.* (1999) and Engström (2002), this research additionally analyses whether the exercise of implied adjusted volatility functions can lead to an improvement in option valuation accuracy. The different types of implied adjusted volatility functions which include variables of moneyness and time to maturity are adapted and modified from the models of Peña *et al.* (1999) and Engström (2002). This study can be viewed as an extension to that of the DVF approach, with the novel feature of implied adjusted volatility. This distinguishes this research from other existing studies.

Studies that employ Australian derivatives data in option pricing are vast. Among those are Pan, Tilakaratne and Yearwood (2003, 2005), Dowling and Muthuswamy (2005), Brown and Pinder (2005), Li and Yang (2009), Buhr (2009), Li, Rose and Buhr (2010), Sharp, Li and Allen (2010), Cummings and Frino (2011), Mimi Hafizah, Abdullah (2011) as well as Li and Mimi Hafizah, Abdullah (2012).

This allows us to infer that the Australian market has become one of the markets which experiences explosive growth in financial sense to be empirically investigated. Only a small number of literature are devoted on studying the implied volatility in Australian options market. This research differentiates itself from other existing literature by investigating the implied adjusted volatility surfaces in the Australian index options using the different Leland option pricing models. This motivates us to study the performance of implied adjusted volatility functions in pricing the Australian index options.

Australian Stock Exchange (ASX) is one of the prime securities exchanges in Australia. ASX accounts for the twelfth world's biggest share market and is the second largest in Asia Pacific region by market capitalisation. In 2010, ASX was reported to be among the ten most robust exchange groups in the world, measured on the basis of market capitalisation. In fact, S&P/ASX 200 (XJO) Index is the largest share market index traded on the ASX, with approximately eighty per cent of total market capitalisation representation on Australian equities market. For that reason, the S&P/ASX 200 index options data is utilized in this paper.

The sample data considered in this study covers the period from April 2001 until the end of 2010. This provides over 105,272 observations[3], which also include the global financial crisis period. The subprime mortgage crisis meltdown in the US which was critical in mid-2007 until the end of 2008 resulted in several ripple impacts on the world's financial market. To the best of our knowledge, research on implied volatility pattern over the period of the 2007 global financial crisis is non-existence. Therefore, this study seeks to motivate future research into Australian market

[3]The S&P/ASX 200 index values of various contracts are acquired daily for over ten years.

volatility by investigating the implied adjusted volatility in the context of S&P/ASX 200 index options in the context of prior, during and after crisis.

This research is further enthused by the claim that there are no definite volatility functions that applied well for options at all moneyness levels, thus eventually elucidate the entire smile volatility (Dumas, Fleming and Whaley, 1998; Hull and Suo, 2002; Engström, 2002; Mimi Hafizah, 2011). This represents another fruitful avenue for this study to fill in. With longer sample period, more refined implied adjusted volatility pattern, an improved implied adjusted volatility function can be pursued at the end of this study.

## 1.2 RESEARCH OBJECTIVES AND CONTRIBUTIONS

The objectives of this research are:

1- To investigate the implied adjusted volatility surfaces of Australian index options using the different Leland option pricing models in the context of prior, during and post global financial crisis in 2007; and

2- To assess whether the use of the implied adjusted volatility functions provides an improvement to option valuation accuracy.

This study contributes to the existing body of knowledge in several dimensions. This research investigates the adjusted volatility surfaces for the S&P/ASX 200 index options. It distinguishes itself from previous studies in which it examines the option implied adjusted volatility.

Apart from that, this study also seeks to examine the different adjusted volatility functions and assessing whether the use of these functions can lead to an improvement in option valuation accuracy. This improved specification of the variation in the adjusted volatility could shed some light on the future refinement of the option pricing model.

## 1.3 THESIS ORGANISATION

This thesis consists of six chapters. Chapter 1 includes background study and motivations; objectives of study and contributions; and, thesis organisation. Chapter 2 provides literature review from previous existing studies. It firstly reviews the literature on the different volatility smile structures across various derivatives, followed by past studies on the volatility functions.

Chapter 3 presents the description of the derivative contracts involved in this study, i.e., the ASX, S&P/ASX 200 index options and its underlying index. The data descriptions and some detailed explanation of the variables used in Leland models are also included. This chapter also outlines the data sampling procedure employed in this study. This is followed by experimental and analysis methodology of this study in Chapter 4.

The results of both objectives, i.e. results on implied adjusted volatility smile pattern and implied adjusted volatility functions are presented in Chapter 5. Lastly, Chapter 6 provides conclusions of this thesis with an overview of the research outcomes, limitations, contributions and the possible avenue for future research.

# CHAPTER TWO

# LITERATURE REVIEW

The BSM model has constituted a major breakthrough in the option pricing realm. Nonetheless, the BSM theory, particularly the constant volatility assumption, came in for criticism due to the inability of the BSM model to handle extreme conditions, especially after the October 1987 market crash. This is evident by the existence of the volatility smile phenomenon which leads to a major inconsistency in the BSM option pricing. In practice, if all assumptions are correct and realistic, then all options should have yielded the same implied volatility. However the volatility implied by those options differs across both moneyness and time to maturity in reality. This elucidates the smile or skew phenomenon, which is failed to be expounded by the BSM model.

Generally, any anomalous pattern can be defined as having skewness or smile, as such that it is resulted from stochastic volatility across a range of strike prices. That is, volatility smile is a measure of how much the BSM's mispricing is related to strike price. This pattern is systematically affected by the degree to which options go deeper into in-the-money (ITM) or out-of-the-money (OTM). On the other hand, term structure describes the changing of volatility across time to maturity.

Macbeth and Merville (1979), Rubinstein (1985), Shastri and Wethyavivorn (1987), Fung and Hsieh (1991), Sheikh (1991), Heynen (1993), Shimko (1993), Xu and Taylor (1994), Bates (1996), Dumas, Fleming and Whaley (1998), Brown (1999), Peña *et al.* (1999), Dennis and Mayhew (2002), Engström (2002), Gemmill and Kamiyama (2000), Cont and Fonseca (2002), Chen and Palmon (2002), Bakshi, Kapadia and Madan (2003), Duque and Lopes (1999, 2003), Bollen and Whaley