The Role of Issuers' Credit Ratings in Dynamic Warrants Pricing

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Abstract

One of major difference of the characteristics between warrants and options in Taiwan is that the former are issued by the qualified securities firms, ruled by Taiwan Stock Exchange (TSEC), and the later offered by the Taiwan Futures Exchange (TAIFEX), who actively list three (the next two quarterly months) or five (the spot month and the next two calendar months) in-the-money series and out-of-the-money ones, respectively. In other words, TAIFEX will regularly list options on TSEC index and others, such as TSEC electric or financial indexes and individual security options, when specific options are in maturity. In contrast, warrants issues could act with a phenomenon of hot issuing period viewed as a kind of herding effect, when the market atmosphere is favorable. Most important, it could be an information asymmetric problem between the warrant issuers and potential investors, since the formers issue the warrant in the beginnings and occupy the largest percentage of the warrants. Besides, options pricing models, releasing the assumptions that volatility process are not constant, have been shown largely improved performance both on in-sample pricing fitness and on out-of-sample forecasting, though the empirical results of deep out-of-money, especially on the short period to maturity are still slightly disappointed. Thus, to investigate how the degree of warrants pricing errors disturbed by the issuers' credit evaluations under controlling the factors proposed both in modified Black-Scholse model, such as stochastic volatility (SV) models and SV with jumps models, and in empirical studies, such as smile effect across moneyness and smirk pattern across time to maturity is the main issue we want to disclosure. The paper will use a comprehensive sample of call and put warrants, amounting to 7089 warrants and valuing to 1.2 trillion N.T. dollars, traded in the TSEC from 2004 to 2008. We hope to contribute the literature on the issues of options pricing model to another viewpoint from the asymmetric information problem among the counterparties.

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1. Introduction

Unlike the U.S. warrants issued by the its underlying stock company and usually combined with a bond (warrant-linked bond), covered warrants, a kind of securitized options, (banked-issued warrants or third-party warrants, warrants hereafter), in Taiwan are issued by a third party, usually a financial intermediary, on the shares of an unrelated company stock or a basket of companies' shares or an index.[1] Warrants, falling under the category of derivative investment instruments, are more particularly appealing to security traders in terms of the volumes of issues and those of the transactions, when they were first allowed to be listed in Taiwan Stock Exchange (TWSE) and introduced into the security market in 1997.[2] Warrants securitize the right, but not the obligation, to buy (call) or sell (put) a certain amount of the underlying security for a preconcerted price up to (American- style warrant) or on (European-style warrant) a preconcerted maturity date. The payoff structure of those warrants is the same as for options, although warrants are legally obligations from the issuer directly to the owner. While in option market, a clearing institution fulfills the obligations of an option writer who fails to fulfill his obligation, there is no such institution in the warrant market.

Since short-selling (i.e., issuing) warrants is impossible for individual investors, no margin accounts are required, more alternatives of underlying stocks of warrant than those of options and the size of the contracts is much smaller than in the options markets, the four facts could be reasons why the former is more attractive to the traders. Beside, the difference between warrants and options in Taiwan is that the former are issued by the qualified securities issuers, ruled by TWSE, and the later offered by the Taiwan Futures Exchange (TAIFEX), who actively lists three (the next two quarterly months) or five (the spot month and the next two calendar months) in-the-money series and out-of-the-money ones accompanying with the index level, respectively. In other words, TAIFEX will regularly list options on TWSE index and

[1] According to the Article 4 of "Taiwan Stock Exchange Corporation Rules Governing Review of Call (Put) Warrant Listings" announced in July, 30, 2007, Any enterprise that simultaneously operates underwriting, trading for its own account, and brokerage or intermediary services may apply for approval as a qualified issuer of call (put) warrants.

[2] It is broadly accepted that these warrants are attractive investment vehicles for two reasons: (1). their leveraging effect and limited loss feature make them attractive to aggressive investors; and (2). they can serve as hedging instruments to reduce the risk exposures arising from other related investments. The numbers of warrants listed in TWSE are from 7 in 1997 to 3,335 in 2007 and related traded volumes in terms of dollars are from 1.96 billions in 1997 to near 254 billions in 2007.

others, such as TWSE electric or financial indexes and individual stock options, when specific options are maturity date.

In contrast, the issuers of warrants are financial institutions. They not only play important roles in pricing and distributing an IPO of warrants but also play a potential link between the before-market pricing and syndication functions with the aftermarket trading and stabilization activities. However, it could be a fact that the activities of warrants issuers before the IPOs and market maker after warrants listed is difficult to reconcile with the assumptions that issuers set the exercise price accurately before a warrant is listed and play the role of making market well after IPOs of the warrants, or quote the warrant fairly at least when the counterparty are almost the individuals after this warrant is traded.

Warrants issuers are the market-makers, the liquidity providers companying with potential inventory risks, and the largest participants who could have assymmetric information relative to their counterparties, usually are individual investors. As a result, the issuers on their trading activities may perform the following functions, the first is to act as a market maker that provides immediacy and ensures smooth trading, another is to distribute warrants to earn premium and then trade to manage its inventory risk and, the last is to proprietarily trade to make profit for them. Many empirical analyses, contributing to the literature on demonstrating that market makers trade to manage their inventory risks, examine market makers' trading activities. Stoll (1976), Ho and Stoll (1983) and Ho and Macris (1984) find evidence of inventory effects. Hasbrouck (1988), Stoll (1989), Madhaven and Smidt (1991), and Foster and Vishwanathen (1993) find weak evidence of short-run inventory effects but strong information effects. Madhavan and Smidt (1993) find strong evidence of both the inventory effects and information effects in price dynamics. Recently, literatures using mostly intra-day evidence examine the specialists trading behavior. For example, in stock market, Hasbrouck and Sofianos (1993), Madhavan and Smidt (1993), and Madhavan and Sofianos (1998) use NYSE data; Hansch, Naik, and Viswanathan (1998), Reiss and Werner (1998), and Naik and Yadav (2003) hire LSE data; Mann and Manaster (1996) with futures market data; Garleanu, Pedersen, and Poteshman (2005) with option market data; Lyons (2001) and Cao, Evans, and Lyons (2006) with foreign exchange data to explain two effects.

In derivatives markets, Ho and Macris (1984) find inventory control effect in

AMEX options where the specialist serves as a monopolist in making the market. Vijh (1988) find very little inventory control effect as the CBOE system where market makers compete and absorb large orders easily. With the EOE option market, where the market-making mechanism is similar to CBOE, Berkman (1996) however find a weak inventory control effect. After market makers supply liquidity the market tend to return to their pre-trade level. Jameson and Wilhelm (1992) find evidences that market makers pay close attention to risk management of their inventory positions.

Easley, O'Hara and Srinivas (1998), for example, suggest option market with better liquidity attracts traders to use this market more. They show that when the leverage implicit in options is large and when the liquidity in the stock market is high, the overall fraction of informed traders is high. The distribution of more derivatives and a better management of the arising risk give rise to possibly higher profits to the derivatives issuers that allow them to put more efforts in making the market. Jameson and Wilhen (1992) emphasize the importance of risk management in market making for option specialists. Thus, two alternative trading patterns may show up when market makers may conduct negative feedback trading or positive feedback trading.

Negative feedback trading suggests selling calls (buying put) when underlying stock price goes up (down). This trading pattern follows from standard microstructure literature where market makers are the supplier of immediacy where they marks up price and sell when the security is in demand and market makers marks down price and buy when the security is not in good demand. Amihud and Mendelson (1980) and Ho and Stoll (1983) both show that specialists will actively control their inventory by setting prices to induce movements towards desired inventory levels. Grossman and Miller (1988) suggest market makers profit from providing liquidity to less patient investors. Hendershott and Seasholes (2007) demonstrate with NYSE specialist daily transaction data that indeed specialist conducts negative feedback trading implying the trading activities of issuers belong to the liquidity providers. Alternatively, positive feedback trading suggests buying calls (selling puts) when underlying stock price goes up (down). Positive feedback trading may arise when issuers manage their risks by adjusting its delta position toward risk neutrality through buying or selling its warrant positions. Trading warrants positions are less capital intensive than the trading of the underlying securities and therefore may be preferable to hedge the inventory risk. Beside, positive feedback trading may also arise as a result of information trading. Market makers react to information trading in the market and trade in the direction of price movement. Kyle (1985), Glosten and Milgrom (1985) and Easley and O'Hara (1987) emphasize the importance of assymmetric information in determining market. An information assymmetric problem could exist between the warrant issuers and potential investors especially on individuals, since the formers issue the warrants in the beginnings and occupy the largest percentage of position on the warrants.[3]

Besides managing their inventory risks, dealers (market makers) could take assymmetrically informed trades is the price leadership effect. Peiers (1997) and de Jong, Mahieu, Schotman and van Leeuwen (1999) examines the quoting behavior of dealers in the Deutsche mark to U.S. Dollar market around Bundesbank interventions and finds evidence of price leadership by Deutsche Bank before the announcement of intervention. Sapp (2002) observes that certain banks consistently incorporate new information into prices before other banks do so and finds evidence that only one side of the price leaders' quotes, that is, ask or bid, provides additional information contributing to price discovery. Ito, Lyons and Melvin (1998) study the change in the pattern of returns volatility in the Tokyo foreign exchange market also conclude empirical observations are consistent with the assumption of privately informed dealers. In stock markets, Huang (2002) finds that, among the NASDAQ market-makers, some provide more timely information, which suggests that they are likely to possess superior information. Heidle and Li (2004) study the quoting behavior of the market-makers affiliated to analysts' brokerage firms. They find strong evidence that these market-makers systematically change their quoting behavior well before the analysts publicly announce the reports containing their investment recommendations and informed market-makers use only one price to signal their private information about the analysts' reports. Finally, in the secondary market for Italian sovereign bonds, Albanesi and Rindi (2000) and Massa and Simonov (2003) found evidence of imitative pricing behaviors and attribute it to the fact that some market-makers are reputed to be better informed. Naranjo and

[3] Assymmetric information, proposed by Kyle (1985) and Glosten and Milgrom (1985), in market microstructure literature assumes the phenomenon that among traders who are classified into those who do not have superior information on market fundamentals and into informed ones who account for price leadership or for signaling through quotes. (Glosten and Milgrom, 1985; Kyle, 1985; Easley and O' Hara, 1987; and Holden and Subrahmanyam, 1992)

Nimalendran (2000) observe that the bid-ask spread changes more around the Bundesbank's unexpected interventions than around its expected interventions, suggesting that the width of the spread may contain some information and suggesting that a dealer with superior private information uses bids and asks separately to signal (or to conceal) information to the market.

While clear evidence would be found in refuting the third objective, the first two objectives may not be mutually exclusive in nature. Based on the literatures discussed above, it is interesting to be disclosed whether issuers do most likely buy (sell) call and sell (buy) put, when market goes up (down), as typical market stabilization, by negative feedback trading rather than the witnessed positive feedback trading, or do support hypothesis that issuers are trading to provide immediacy to the market. Not in the case of providing immediacy, they may trade in positive feedback either for information reason or rather simply they trade to manage their inventory risk. Prior literature also suggests very limited information trading can be found in the option market due to its relatively low liquidity (Chan, Chung, and Johnson, 1993; Chan, Chung and Fong, 2002), thus, we use another derivatives, warrants, can contribute to the fields in this paper.

As smooth trading in the warrant market may add to the depth to the market that eventually leads the issuance of more warrants. Issuers have charged a premium when the warrants were listed and they have inventory costs as liquidity providers after the warrants were issued. In contrast, issuers could be viewed as informed traders to gain abnormal profit since the market is monopoly on a specific warrant between the issuer and other traders, especially those who are individual investors. The structure of the market is also like a monopolistic competition, a kind of imperfect competition, among the issuers on those warrants that target the same underlying stock with different exercise price and time to maturity. That is to say, warrants, issued by lots of issuers, with the similar contract-specific characteristics, such as underlying stock, moneyness, remaining time to maturity and multiplier, have distinctive turnover rates and premiums. Thus, how to set a fair listing price using suitable algorithms proposed by option pricing models,[4] how to remain a regular trading activity beyond the listed

[4] One of the most important concerns is to find the formulated-issue price set by the issuers before the warrant is allowed to be listed in the market. Empirical evidences on literatures related to the options pricing models, basing on Black-Scholes type and extending to those whose volatility are stochastic (SV), SV with jumps in returns process (SVJ) and SV with stochastic interest rates (SVSI),

date and how to identify whether issuers play roles in making market, liquidity providing of the warrant, for the newly traded warrants or act as a premium-searchers like assymmetric information theory predicted in microstructure fields, are three major particular concerns in the paper we hope to investigate.

After roughly reviewing the report of the listed warrants on the Market Observation Post System disclosed by TWSE from 1999 to 2008, we can find lots of interesting phenomenon stated as follow. The first, warrants, issued by qualified issuers, have distinct theoretical premiums and *ex ante* returns pattern on the same underlying stock with similar exercise price and maturities under other conditions are equal. However, warrants issuers could act with a phenomenon of hot issuing period viewed as a kind of herding effects, when the market atmosphere is favorable to them. We investigate the quality of liquidity in terms of the liquidity ratio of the warrants trades and other measureable proxy, and decompose the pricing errors from the contract-specific characteristics, functions of liquidity providers performed by issuers and issuers-specific identities. Another we test how the degree of warrants pricing errors disturbed by the issuers' credit evaluations in Black-Scholes (1973, hereafter B-S) and modified B-S models, Hseton's (1993) stochastic volatility model (SV) and Bates' SV with jumps model (SVJ). Finally, we use a comprehensive sample of call and put warrants, accounting to 7089 warrants and valuing to 1.2 trillion N.T. dollars, traded in the TWSE from 2004 to 2008. We hope to contribute the literature on the issues of options pricing model to another viewpoint from the assymmetric information problem among the counterparties of warrants traders.

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have been shown largely improved performance both on in-sample pricing fitness and on out-of-sample forecasting, although the empirical results of deep out-of-money ones, especially on shorter period to maturity are still slightly disappointed. (Melino and Turnbull, 1990; Day and Lewis, 1992; Rubinstein, 1994; Bakshi, Cao, and Chen, 1997; Nandi, 1998; Bates, 1996a and 2000; Lin, Strong and Xu, 2001; Bates, 2003; Chen and Gau; 2008, and among others)

2. Data Descriptions and Sample Selection Criteria

We access the daily-closed prices of warrants and related underlying stocks traded in Taiwan Stock Market from 2004 to 2008 as our samples.[5] A brief summary of the preliminary data we collected are shown as Table 1.

From Table 1, we can roughly find that the warrants market is full of vitality from 1999 to 2008, in terms of trade volumes measured by values and units, of the numbers of issues and ratio on the values of warrants to the total security market. The fact, that total traded values of warrants occupy about from .22% and .77% on that of the market in 1999 and 2008, shows warrants market have been flourishing.

< Insert Table 1 about here>

In our data, we plan to discard the uninformative options records in samples by the following categories. First, since the price of the warrants, especially on the deep out-of-money, whose maturity day is less than 5 calendar days is erratic, we use the daily traded warrants with the maturities larger than 5 calendar days to expiration as our samples. Second, warrants violate the European-style boundary conditions, for example, the condition is $C < S - Ke^{-r\tau}$ for call warrants. And finally, the daily warrants with the strike/spot price ratio (moneyness, denoted as S/K for call warrants, K/S for put warrants) are from 0.5 to 1.5. After discarding samples with the criteria discussed above and considering the underlying stocks listed and traded in TWSE market, the total sample includes 1122 warrants with 493,613 daily trading records in our study.

As for the risk-free rates, similar to the popularly cited literatures, studied empirically in U.S. market, used the yield on the U.S. treasury bills with maturity closest to the option maturity date as the risk-free interest rates, for example, Bodurtha and Courtadon (1987), Bates (1996b), and Sarwar and Krehbiel (2000), we use the monthly deposit interest rate averaged from one-month Board Rate[6] (rolled over each month), calculated from the average on the five major commercial banks including, Bank of Taiwan, Taiwan Cooperative Bank, First Bank, Hua Nan Commercial Bank and Chang Hua Bank and disclosed on Web. site on Central Bank of R.O.C. from

[5] Since the numbers of listed warrants are 7 and 14 in 1996 and 1997 and related trade volumes occupied less compared to those after 2003, we exclude the samples of these years.

[6] Interest rates are published on the Central Bank website.

2004 to 2008 as the proxy for risk-free rate.

The credit rating of the issuers are collected from the reports disclosed by Taiwan Ratings Corporation, Fitch Ratings Limited Taiwan Branch, Moody's Investors Service, and/ or from Standard and Poor's, respectively. The daily percentage liquidity ratio of warrants, trade volume in terms of ten thousand NTD, and moneyness are collected from the TEJ database and calculated based on the operation definition discussed in detailed on next chapter.

< Insert Table 2 about here >

From Table two, we can find that the warrant underlying on “the electronic parts or semiconductor industry” occupied about 30.29% (the first SIC code 23 and 24), and “financial and insurance industry (the first SIC code 28)” occupied about 11.45%, are the most favorable ones that issuers are interested. The average pricing errors of the total market is about 0.301 NTD with a standard deviation, 0.555. We can find the results of option pricing errors, the difference between daily closed price and theoretical option price estimated from B-S model, is similar to the literature says that the pricing errors have an skewing to the right, a estimated value of 6.735, and lepto-kurtosis, a estimated value of 122.973, which both are mostly contributed by the “the electronic parts or semiconductor industry” with a skewness value 7.530 and a kurtosis value 134.578. That is to say B-S model could be a biased estimator when we calculate the theoretical price of a warrant, since most of the sample are the out-of-money ones which shows a right-skewness pattern; an unconsidered fact the volatility pattern of underlying assets is stochastic and volatility clusters or could has a jump-phenomenon which the kurtosis of pricing errors is loptic. Thus, we use another two SV and SVJ models in this study for the sake of controlling the pricing errors caused from the third and fourth moments and then to focus on discussing how the credit rating and related microstructure variables affect the pricing errors of warrants.

3. Methodology

To investigate how credit rating and liquidity provider affect the pricing errors of warrants, we control the major cause of option pricing errors sources from underlying assets prices dynamics and volatility pattern based on the studies of alternative option pricing models.

Option pricing models originated from Black-Scholes (1973) have witnessed an explosion of new approaches, since lots of literatures show B-S model is subject to systematic biases originated from the violation of the normal distribution assumption on the underlying returns. [7] The negative implicit skewness will cause the out-of-the-money option price bias, whereas the implicit leptokurtosis will raise the prices of deeply in-the-money and out-of-money options and lower prices of near-the-money options. The first innovation of underlying price process is induced of the stochastic volatility (SV) option pricing models, such as Hull and While (1987), Scott (1987), Wiggins (1987), Melino and Turnbull (1990), and Heston (1993), incorporate the leptokurtosis or excess kurtosis of the underlying asset returns by allowing the volatility process to behave randomly.[8] Unlike the viewpoint of Merton (1976a) who assumes the jump risk is diversifiable and therefore nonsystematic, Bates (1991) deal the jump risk as systematic and provided a European option pricing model which can capture stochastic skewness by randomizing the mean jump size parameter and the correlation parameter between the return and the stochastic volatility process, and offered an empirical study based on the closed form solution of Heston (1993), with a diffusion-jump stochastic volatility process (SVJ).

Bakshi, Cao and Chen (1997) evaluated the relative in-sample fitness, out-of-sample pricing and hedging performances for S&P 500 index options among various options pricing models, including SV, SVJ, and SV with stochastic interest option pricing models and suggest that the option pricing model of SVJ performs best that SV and SV with stochastic interest model. They argued that jumps included in

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[7] For example, Melino and Turnbull, 1990; Day and Lewis, 1992; Rubinstein, 1994; Bakshi, Cao, and Chen, 1997; Nandi, 1998; Bates, 1996a, 2000; Lin, Strong and Xu, 2001; Chen and Gau, 2008; and among others

[8] Black and Scholes (1973) assumed that the source of volatility risk comes from stochastic returns of the underlying, however, the SV option pricing models allow the pricing risk to come from both the stochastic process of price and the stochastic process of volatility. To model the stochastic process of volatility in the SV option price, one has to specify the market price of volatility risk, the volatility of variance, and the correlation between underlying price (return) and related volatility.

return processes play important roles in pricing options, although the jump effect is not a significant factor in option hedging strategies.

Thus, for the sake of accurateness of theoretically estimated prices of warrants we use three approaches to estimate the pricing errors of warrant i in day t, $e_{i,t}$, defined by the difference between market prices and model prices, among alternative pricing models, saying B-S, SV and SVJ.

Black and Scholes (1973) assumed that the volatility of the returns is constant and used the concept of hedging portfolios formed by options and their underlying stocks to derive the non-dividends European option theoretical valuation-formula as,

$$C(S,\tau) = SN(d_1) - Ke^{-r\tau}N(d_2)\,, \tag{1}$$

where $d_1 = \dfrac{\ln(S/K) + [r + 0.5\sigma^2]\tau}{\sigma\sqrt{\tau}}$; $d_2 = d_1 - \sigma\sqrt{\tau}$; S, K, σ , and $\tau \equiv T - t$ represent the spot rate, exercise price, the constant volatility of the spot return, and the time to maturity, respectively. According to the put-call parity, European style put option can be obtained as follows:

$$P(S,\tau) = Ke^{-r\tau}N(-d_2) - SN(-d_1)\,. \tag{2}$$

Many studies, such as Bollerslev, Chou, and Kroner (1992), Heieh (1989), Taylor and Xu (1994) and Poon and Granger (2003), have argued that exchange rate volatility follows a stochastic process. Specifically, tails of the distribution computed with intraday or daily market prices are fatter than those of the lognormal distribution, exhibiting leptokurtosis (Gesser and Poncet, 1997). Thus, the estimated implied volatility from the constant volatility assumption from the B-S model has been shown a biased estimate. Various stochastic volatility option pricing models, such as Hull and While (1987), Scott (1987), Wiggins (1987), Melino and Turnbull (1991), Heston (1993), and Bates (1996), were developed to release the unrealistic assumption, the constant return volatility.

This return distributional assumption that includes stochastic volatility and jump process, for stocks in Bakshi, Cao and Chen (1997) and for currency prices in Bates (1996a), offers a sufficiently versatile structure that can accommodate most of the desired features. Releasing the assumption that correlation between volatility and the spot return is zero, Heston (1993) obtained a closed-form solution for the European option on an asset, including stock, currency and bond, with mean-reverting square-root stochastic volatility (SV model).[9] The derivation relies on properties of the conditional distribution and involves numerical integration of the characteristic function of the probability process. The European call option on currency follows:

$$\begin{aligned} C &= e^{-r\tau} E^* \max(S_\tau - K, 0) \\ &= e^{-r\tau} \left[\int_X^\infty (S_\tau - K) f^*(S_\tau) dS_\tau \right] \\ &= S e^{-r_F \tau} P_1 - K e^{-r_D \tau} P_2 \end{aligned} \tag{3}$$

C, S, and *K* have the same meaning in the Black-Scholes model. In order to get a closed-form solution, Heston (1993) used the Fourier transformation and derived the probability density function P_j :[2]

$$P_j(x, v, t; \ln[K]) = \frac{1}{2} + \frac{1}{\pi} \int_0^\infty \mathrm{Re}\left[\frac{e(-i\varphi \ln(K)) f_j(x, v, t; \varphi)}{i\varphi} \right] d\varphi, \tag{4}$$

where j=1, 2, Re means the real part of the square bracket, $i = \sqrt{-1}$, $f_j(x, v, t; \varphi)$ represents the characteristic functions of the conditional probability P_j.

$$P_j = \frac{1}{2} + \frac{1}{\pi} \int_0^\infty \mathrm{Re}\left[\frac{\exp\left(-i\varphi \ln(K)\right) \cdot f_j}{i\varphi} \right] d\varphi, \quad j = 1, 2 \tag{5}$$

where f_j, $j = 1, 2$ is the characteristic function of parameters set, $\varphi = \{\kappa^*, \theta^*, \sigma_v, \rho\}$.[10]

Under the risk-neutral measure, Bates (1996a) proposed a model which combined the concept of stochastic volatility (Heston, 1993) to catch the "skewness premium" with jumps process (Merton, 1976) to price the possibility of the jump risk in security price dynamics (SVJ model). The stochastic volatility with jumps option pricing models Bates proposed as,

Jump model is also can be used the Fourier transformation and be derived the probability density function P_j [11]:

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9 Heston (1993) asserted that the correlation between underlying asset returns and its volatility affects the skewness and leptokurtosis of the distribution of the underlying asset returns which follow the risk-neutral pricing probabilities derived by Cox, Ingersoll, and Ross (1985)

10 See Heston (1993) for more details on the derivation of the characteristic functions.

11 See Bates (1996a), and the proof in appendix of Bakshi, Cao, and Chen (1997) for more details on the derivation of the characteristic functions.

$$P_j(x,v,t;\ln[K]) = \frac{1}{2} + \frac{1}{\pi}\int_0^\infty \mathrm{Re}\left[\frac{e(-i\Phi\ln(K))f_j(x,v,t;\Phi)}{i\Phi}\right]d\Phi\,, \tag{6}$$

where j=1, 2, Re means the real part of the square bracket, $f_j(x,v,t;\Phi)$ represents the characteristic functions of the conditional probability P_j and $\Phi = \{\lambda, \mu_J, \sigma_v^J, \kappa_J^*, \theta_J^*, \sigma_v, \rho_J\}$ are the parameters set.

Given the no-arbitrage condition and the price of a call option, C, we can use the put-call parity to obtain the European put option price as,

$$P = C - S + Ke^{-r\tau}\,. \tag{7}$$

In short, we adopt Heston's (1993) SV and SV with jump model (SVJ) to explore the stock prices process implicit in the options based on the model of SV and SVJ models and its relative effect of volatility and jumps in option pricing literatures, against B-S model to study how extra potential sources, specifically from the aspects of market microstructure, disturb the warrants prices. Since some of the warrants traded in TWSE are American style option, we employ the quadratic approximation method of Barone-Adesi and Whaley (1987) to adjust the early exercise premium to derive a more accurate empirical study.[12]

To explore and obtain the warrants pricing errors caused from other sources not discussed yet in option pricing models, we first control the volatility and jump effects from three alternative options pricing models, B-S as a bench mark models and SV and SVJ models as for competing ones for the two effects, reviewed above.

$$e_{i,t} = C_{i,t} - C_{i,t}^{\text{model}}\,, \tag{8}$$

where $C_{i,t}^{\text{model}}$ is calculated from three models, i.e., B-S, SV and SVJ, and $C_{i,t}$ is the market price.[13] By the put-call parity, the European style put warrant can be obtained. The detailed algorithms are shown in Appendix 2. And then we take the pricing errors estimated from equation (8) to examine the relationship between pricing errors and issuers-specifications as following two regression models,

[12] Barone-Adesi and Whaley (1987) used the quadratic approximation method to price American call and put options on an underlying asset with cost-of-carry rate.

[13] If the warrant is American type, we use the quadratic approximation method of Barone-Adesi and Whaley (1987) to adjust the early exercise premium to derive a more accurate empirical study.

$$e_{i,t} = \beta_0 + \beta_1 CR_{i,t} + \beta_2 \tau_{i,t} + \beta_3 IV_{i,t} + \beta_4 Volume_{i,t} + \beta_5 Mony_{i,t} + \varepsilon_{i,t}\,, \tag{9}$$

and,

$$\begin{aligned} e_{i,t} = \beta_0 + \beta_1 CR_{i,t} + \beta_2 \tau_{i,t} + \beta_3 IV_{i,t} + \beta_4 Volume_{i,t} + \beta_5 Mony_{i,t} \\ + \beta_6 ALR_{i,t} + \beta_7 (\ln r_{C_{i,t}} / \ln r_{S_{i,t}}) + \varepsilon_{i,t} \end{aligned}\,. \tag{10}$$

Equation (9) is set to a priori test to observe the pure effect of the crediting rating on pricing errors, and then we extend the model by adding two independent variables, namely ALR, measuring the liquidity of warrants, and ratio on daily log-return of the warrant to underlying stock

The subscript i and t represent the i^{th} warrant on date t. $CR_{i,t}$, is a dummy variable of the credit rating of the issuer. If the credit rating is less than the A class, then the value is equal 1, otherwise the value of the dummy is 0. $IV_{i,t}$ is the implied volatility estimated from the three option pricing models, B-S, SV and SVJ; $Volume_{i,t}$ is the trading volume in terms of 10 thousand NTD.

Two contract-specific variables, $Mony_{i,t}$ and $\tau_{i,t}$, measured in one hundred trading days, are the moneyness, defined as $S_{i,t}/K_i$ for the call warrant, and the remaining time to expiration for the i^{th} warrant in day t, respectively.

We use variable $ALR_{i,t}$, which is on one thousand units (NTD), to investigate functions of liquidity provider of the issuers after the warrants are listed to trade. The independent variable, $ALR_{i,t}$, is the daily liquidity ratio of a warrant and we plan to use well-popular measure used in market microstructure literatures, Amivest Liquidity Ratio (Groth and Dubofsky, 1984; Cooper, Groth and Avera, 1985; Amihud, Mendelson and Lauterbach, 1997; Berkman and Eleswarapu, 1998) shown in equation (10).

$$ALR_{i,t} = \frac{C_{i,t} \cdot Volume_{i,t}}{\left| \dfrac{C_{i,t} - C_{i,t-1}}{C_{i,t-1}} \right|}\,, \tag{11}$$

where, $C_{i,t}$ ($C_{i,t-1}$) and $Volume_{i,t}$ represent call warrant i closing price and daily trade volume at day t (t -1), respectively.

Finally, even a premium has been charged when the warrants were issued, but the issuer still has inventory risk when the price of underlying stock rises. In advanced, the structure of a listed warrant is similar to a monopoly market between the issuer and other traders, especially those who are individual investors. The issuer, viewed as an informed trader, has an incentive to gain abnormal profits for himself more or less. To investigate whether issuer manipulates the price of the warrants or not, we use a ratio, in terms of percentage, on daily return of the warrant to underlying stock.

$$\ln r_{C_{i,t}} / \ln r_{S_{i,t}} \ , \tag{12}$$

where, $\ln r_{C_{i,t}}$ and $\ln r_{S_{i,t}}$ are the nature-log daily return of i^{th} the warrants and underlying stock, respectively, on date t.

4. Empirical Results

4.1 Primarily Results

To investigate the pricing errors shown in Table two, we present the summary in eighteen classified industries and the market firstly, and then to study roughly from the pricing errors patterns based on B-S model.

< Insert Table 3 about here >

Table 3 summarizes the statistics of variables used in the paper. The first and most important variable, credit rating of warrant issuers, is defined as a binary variable, which is equal to, if the credit rating is less than the A class, otherwise the value of the dummy is 0. There are 918 warrants, including 403448 trading records, issued by the A (and above A) classes security companies and are 204 warrants, including 90165 trading records, issued by the B (and below B) classes security companies, respectively. [14] The mean of implied volatility estimated from B-S model is 42.35% with a standard deviation 10.17%, a slightly right skewed, 0.1308, and a platykurtic but near a normal kurtosis, 2.6323. It is interesting to compare these statistics with the pricing errors of the total market values shown in the last row Table 2. The pricing errors have a skewing to the right, an estimated value of 6.735, and lepto-kurtosis, an estimated value of 122.973. If the source of the pricing errors majorly comes from the implied volatility, we would have similar patterns both of pricing errors and implied volatility. These results can also be found in Figure 1.

< Insert Figure 1 about here >

Apparently, it could exist other factors, that could have not reviewed, affect the pricing of warrant. Trading volume in NTD, used as an activity measure in the last study in our paper, shows an average value about 9.8 millions with a value of standard deviation, 12.90 millions. Daily log-return on underlying stocks and warrants both appear a reverting pattern with a near zero mean; the underlying stock seemly more violate about seven times than that of warrants in terms of standard deviations. It is also can be proved from both the range of the Max-min values and the estimates of fourth moment. From the viewpoint on leverage effects, return process of derivatives would be more violate than that of underlying, it seemly shows one of clues on

[14] For the sake of academic neutrality, we don't hope to release the name of the security companies. But if in necessity, we will provide the detail data of credit rating.

discovering pricing error on warrants pricing in Taiwan![15]

Finally, we use Amivest Liquidity Ratio (ALR) in one thousand NTD to measure the effect of liquidity on the pricing errors of warrants. Average daily liquidity is about 23.49 thousand with a standard deviation 113.18 thousand. By the way, ALR liquidity ranges from zero to 16720.47 thousand and has a skewness with 43.47 and a kurtosis with 4308.33, both reveals a fact that most warrants are liquid, but in some cases especially on deeply out-of-money and near maturity date, they are illiquid; in other cases especially on the firstly listed day, they have a extreme liquidity in terms of ALR functioned with trading values; since the trading motivation inspired by issuers who hope to manage the inventory risk they will face in the future.[16]

4.2 Regression Analysis on Decomposing Warrants Pricing Errors

We use two regression models to study the pricing errors estimated from equations (9) and (10) to examine how the theoretical pricing model, $\tau_{i,t}$, $IV_{i,t}$ and $Mony_{i,t}$ used in the field of empirical option pricings, contract-specific characteristics, $Volume_{i,t}$, $ALR_{i,t}$, and $(\ln r_{C_{i,t}} / \ln r_{S_{i,t}})$ discussed in microstructure area, and issuers-specifications, $CR_{i,t}$,the major issues in the paper, affect the warrant price dynamics. Empirical results are shown in Table 4, “Regression Analysis on Decomposing Warrants Pricing Errors by Industry”, and Table 5, “Decomposing Warrants Pricing Errors by Using Theoretical Pricing, Contract-Specific Characteristics, and Issuers-Specifications”. The reason why using two regressions to analysis the pricing errors is that we firstly use standard measurements, such as time to maturity, implied volatility, trading volumes and moneyness, in option pricing literatures and use credit rating of issuers as an interested independent variables to see how of rating of issuers’ credit affects the pricing after controlling the explainers argued in smile and smirk effects.

[15] It sounds an interested idea that to compare the price dynamics of options listed in TAIFX with those with warrants on the same underlying securities and related compounded securities, such as ETF 50. But for the sake of focus on investigating how the effect of issuers’ credit rating disturbs the pricing dynamics, the issues will leave to our proceeding working paper.

[16] In the paper, we wish to use the term, “inventory risk” but not the one, “trading strategy” to convey an idea that we believe all participants, including the issuers and other investors, are well-behaved! But, in practice, if the issuers have motivation to own the most “chips” in this game with their counterparties, usually are the individual investors, it could be doubtable that warrants markets are fair!

In Table 4, firstly, we can find a consistent results of cross section analysis from the following eight Industry, Food (the first two SIC, 12), Plastic (13), Electric Machinery (15), Iron & Steel (20), Rubber (21), Electronic parts and Semiconductor (23 & 24), Shipping & Transportation (26), and Financial & Insurance (28). The coefficients are statistically significant all at 1% level and positive coefficient on the estimates of credit rating, β_1, showing the hypothesis we discussed in Chapter 2 and 3, that if the credit rating of a warrant issuers is evaluated from B to A class, thus the pricing errors will reduce from 1.9% (in Rubber Industry, 21) to 8.3% (in Food Industry, 12), since the *CR* variable is set to 1 if the credit rating belongs to class B.

< Insert Table 4 about here >

Secondly, time to maturity, $\tau_{i,t}$ is ambiguous to pricing errors: Food, Sipping & Transportation, and Financial & Insurance have a negative coefficient, i.e., nearer to maturity more pricing errors they have. Generally, the pricing errors will fall as close to maturity day, since the premium of warrant, including intrinsic and time value, almost just includes its intrinsic value. Thus, in above situation, the negative coefficients are tricky. We will leave this phenomenon as our next further studies.[17] Thirdly, estimated parameters, β_3 of implied volatility, $IV_{i,t}$, has a consistently negative effect of pricing errors from highlighted industries of the third column in Table 4. This shows a smile effects in terms of B-S model, since most of our sample are not the at-the-money warrants. One unit volatility implicit in market price of warrant increases will reduce the pricing errors, for example 28.6% in Electronic parts and Semiconductor industry, implying that the difference between market price and theoretical price in B-S model falls. In our sample, the Financial & Insurance industry is the most sensitive one, near a value of 50%, on the implied volatility to warrant pricing errors.

Moreover, the variable, $Volume_{i,t}$, has a positive relationship with pricing errors, which means more the trading volumes more pricing errors have. This phenomenon is consistent with the argument proposed by the Black (1986) and Easley, O'Hara and Srinivas (1998). Finally, we find statistically significant coefficients between

[17] But we guess a possibly potential reason could explain: negative correlations of the underlying stock price of these three industries with other five industries. Also, it could be caused by the same inference as stated in footnote 16.

independent variable, moneyness, $Mony_{i,t}$, and dependent variable, pricing error $e_{i,t}$. According the smile effect of empirical studied in options pricing, more near the at-the-money warrants from the out-of-money side, the warrant' pricing will reduce according the smirk effect. But, if the moneyness of a warrant come from in-the-money category to at-the-money or even to an out-of-the one as the underlying stock price rises/falls (call warrant/ put warrant), the volatility smirk effect will slow the pricing errors. The conflicts discussed above is caused we don't classify the changing patterns either the moneyness of warrant go to near the 1 (at-the-money, i.e., $S_{i,t} = K_i$) or leave from the 1 momeyness.

From the view point of the total market samples, which account weightily estimating process with numbers of listed warrants that majorly target on the two industries, Electronic parts and Semiconductor and Financial & Insurance, of the regression results are shown in Table 5. Consistently, the estimated coefficients of explained regressors on dependent variables earn similar results in Table 4, but these parameters are more statistically significant than those in Table 4. The parameters, except for the variable, implied volatility, are indifferent among three alternative models, B-S, SV and SVJ models.

< Insert Table 5 about here >

In short, we find both statistically and economically significant-estimated parameters, even by adding another two variables, including liquidity ratio, $ALR_{i,t}$, and daily return of the warrant to underlying stock, $\ln r_{C_{i,t}} / \ln r_{S_{i,t}}$, to investigate whether or not issuer manipulates the price of the warrants in Table 5. The Amivest Liquidity ratio owns a negative correlation that , show more the warrant are liquid less the pricing errors have. This phenomenon contributes similar evidence to the microstructure literatures. The coefficients of daily return of the warrant to underlying stock are negative and imply that the asynchronous and assymmetric patterns on the returns process between warrants and underlying stock. 1% increase (decrease) in stock price, reducing the pricing errors, less than 1% increase (decrease) in a call warrant price. But, we should consider the leverage effect, defined as the assymmetric return changes between warrant and related underlying stock in the paper, but we have include the effect into our another available paper.

5. Conclusions, Discussions and Further Research

5.1 Conclusions

In the paper, our major investigation is on how the credit rating of warrants issuers and study the quality of liquidity in terms of the Amivest Liquidity Ratio and other measureable proxy, such as trading volumes and ration on returns of warrant to stock, affect warrant pricing errors in TWSE by decomposing the pricing errors from the contract-specific characteristics, functions of liquidity providers performed by issuers and issuers-specific identities.

We find the credit rating of a warrant issuers is evaluated from B to A class, the pricing errors will reduce from 1.9% (in Rubber Industry, 21) to 8.3% (in Food Industry, 12), and on average 6.32% falling of the errors in terms of the total markets. The parameters, except for the variable, implied volatility, are indifferent among three alternative models, B-S, SV and SVJ models. Variable, time to maturity, $\tau_{i,t}$, is ambiguous to pricing errors: generally, the pricing errors will fall as close to maturity day, since the premium of warrant, including intrinsic and time value, almost just includes its intrinsic value. Thus, in above situation, the negative coefficients are tricky. We will leave this phenomenon as our next further studies. Implied volatility, $IV_{i,t}$, has a consistently negative effect of pricing errors and shows a smile effects in terms of B-S model, since most of our sample are not the at-the-money warrants. $Volume_{i,t}$, the variable has a positive relationship with pricing errors. This phenomenon is consistent with the argument proposed by the Black (1986) and Easley, O'Hara and Srinivas (1998). We fund conflicts occur of the smile effect of empirical studied in options pricing still exist and the volatility smirk effect will slow the pricing errors would be caused by that we don't classify the changing patterns in terms of raise or fall of price change on underlying stock. Moreover, Amivest Liquidity ratio shows more the warrants are liquid, less the pricing errors have. The coefficients of the ratio on daily return of the warrant to underlying stock are negative and imply that an asynchronous assymmetric patterns on the returns process between warrants and underlying stock.

How the credit rating, the quality of liquidity of warrants issuers and the ratio on daily return of the warrant to underlying stock disturb the formation of warrant prices, are our core study issues in the paper.

In this study, we believe all participants, including the issuers and other investors, are well-behaved, especially on the issuers who are viewed as an informed and own the largest position of the warrants they issued! But, if the issuers have motivation to own the most “chips” in this game with their counterparties, usually are the individual investors, it could be doubtable that warrants markets are fair! This proposition are prove by the papers.

Another contribution is to investigate how the degree of warrants pricing errors disturbed by the issuers’ credit evaluations by using three option pricing models, the B-S, SV and SVJ models under both smile effect across moneyness and smirk pattern across time to maturity are controlled. Finally, in the paper, we will use a comprehensive sample of call and put warrants, accounting to 7089 warrants and valuing to 1.2 trillion N.T. dollars traded in the TWSE from 1999 to 2007. We hope to contribute the literature on the issues of options pricing errors to another viewpoint from the assymmetric information problem among the counterparties of warrants traders. We believe the paper contributes the academics and the practices learning about the quality of liquidity provider of warrants issuers by a conscientious and careful empirical methodology and carries the achievements of the filed beyond the option pricing models say.

In further research, we will consider how the leverage effect, defined as the assymmetric return changes between warrant and related underlying stock, affect the pricing errors by investigating two return’s dynamics in our work.

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Table1. Issued Numbers, Traded Volumes in terms of Values and Units of Warrants Market

year	*Numbers of Warrants Issued*		*Traded Volumes in terms of values (billion, NTD)*		*Traded Volumes in terms of units (billion)*		*Ratio on the volumes ($) of warrants to the market*
	level	*Rate of growth*	*level*	*Rate of growth*	*level*	*Rate of growth*	
1999	66		64.78		3.81		0.22%
2000	103	56.06%	162.26	150.48%	11.59	204.20%	0.53%
2001	110	6.80%	28.44	-82.47%	7.78	-32.87%	0.15%
2002	158	43.64%	74.47	161.85%	1.91	-75.45%	0.34%
2003	408	158.23%	118.34	58.91%	48.84	2457.07%	0.58%
2004	480	17.65%	207.75	75.55%	108.55	122.26%	0.87%
2005	984	105.00%	142.36	-31.48%	12.26	-88.71%	0.76%
2006	1,445	46.85%	175.07	22.98%	149.12	1116.31%	0.73%
2007	3,335	130.80%	253.18	44.62%	259.79	74.22%	0.77%
2008	5,732	71.87%	275.82	8.94%	300.08	15.51%	2.36%

Source: Summary from the “Market Observation Post System” disclosed by Taiwan Stock Exchange Corporation.

Table 2. Pricing Errors on Warrants Calculated from Black and Scholes (1973) Model

This table reveals option pricing errors, the difference between daily closed price and theoretical option price estimated from B-S model, in eighteen industries.

Industry: First two SIC Code	Industry: Identity	Numbers of Samples (%)	Mean	Std. deviation	Skewness	Kurtosis
11XX	Cement	7464 (1.51)	0.281	0.453	2.377	12.891
12XX	Food	10161 (1.04)	0.238	0.449	2.753	13.712
13XX	Plastic	15843 (1.63)	0.310	0.494	3.466	18.733
14XX	Textile	8500 (0.89)	0.283	0.441	3.381	19.306
15XX	Electric Machinery	7731 (0.82)	0.274	0.344	2.562	12.035
16XX	Electrical & Cable	4944 (0.53)	0.263	0.372	2.157	7.771
17XX	Chemical Industry	13035 (1.40)	0.308	0.473	2.728	12.805
18XX	Glass & Ceramic	110 (0.01)	0.426	0.309	0.735	3.211
19XX	Paper & Pulp	1743 (0.19)	0.238	0.319	3.016	16.156
20XX	Iron & Steel	22568 (2.46)	0.276	0.403	2.752	13.834
21XX	Rubber	10418 (1.16)	0.306	0.464	2.804	13.435
22XX	Automobile	5242 (0.59)	0.266	0.414	3.296	16.006
23XX 24XX	Electronic Parts/ Semiconductor	266408 (30.29)	0.311	0.626	7.530	134.578
25XX	Building Material & Construction	15241 (2.49)	0.273	0.455	4.865	50.974
26XX	Shipping & Transportation	29753 (4.98)	0.261	0.445	5.383	63.401
27XX	Tourism	3698 (0.65)	0.217	0.275	2.138	12.444
28XX	Financial & Insurance	64630 (11.45)	0.322	0.490	2.858	14.447
29XX	Trading & Consumers Goods	6124 (1.23)	0.266	0.573	4.433	32.720
	Market	493613 (100)	0.301	0.555	6.735	122.937

Table 3. Descriptive Statistics for the Variables

Table 3-1

		Numbers of Warrants	Numbers of Observations
Credit Rating	Above (including) A class of issuers on warrant	918	403448
	Below A Class rating of issuers on warrant	204	90165
	Total	1122	493613

Table 3-2

The implied volatility estimated from B-S model. Trading volume in NTD, used as an activity measure in the last study in our paper. Daily log-return on underlying stocks and warrants both appear a reverting pattern with a near zero mean; the underlying stock seemly more violate about seven times than that of warrants in terms of standard deviations. Finally, the Amivest Liquidity Ratio (ALR) in one thousand NTD to measure the effect of liquidity on the pricing errors of warrants.

	Mean	Max.	Min.	Standard Deviation	Skewness	Kurtosis
Implied Volatility	0.4235	0.7244	0.1233	0.1017	0.1308	2.6323
Trading Volume (NTD)	979.8241	128970.00	0.0000	1894.2450	9.4071	204.6202
Log Return on Stock	-1.13E-05	6.8669	-4.8752	0.4577	6.4007	72.3020
Log Return on Warrant	-6.92E-07	3.1631	-3.3443	0.0680	8.2314	293.0955
ALR	23.4888	16720.470	0.0000	113.1869	43.4684	4308.3290

Table 4. Regression Analysis on Decomposing Warrants Pricing Errors by Industry

Regression models is in equation (9). The subscript *i* and *t* represent the i^{th} warrant on date *t*. $CR_{i,t}$, is a dummy variable of the credit rating of the issuer. If the credit rating is less than the A class, then the value is equal 1, otherwise the value of the dummy is 0. $IV_{i,t}$ is the implied volatility estimated from the three option pricing models, B-S, SV and SVJ; $Volume_{i,t}$ is the trading volume in terms of 10 thousand NTD. Two contract-specific variables, $Mony_{i,t}$ and $\tau_{i,t}$, measured in one hundred trading days, are the moneyness, defined as $S_{i,t}/K_i$ for the call warrant, and remaining time to expiration, respectively. $e_{i,t} = \beta_0 + \beta_1 CR_{i,t} + \beta_2 \tau_{i,t} + \beta_3 IV_{i,t} + \beta_4 Volume_{i,t} + \beta_5 Mony_{i,t} + \varepsilon_{i,t}$

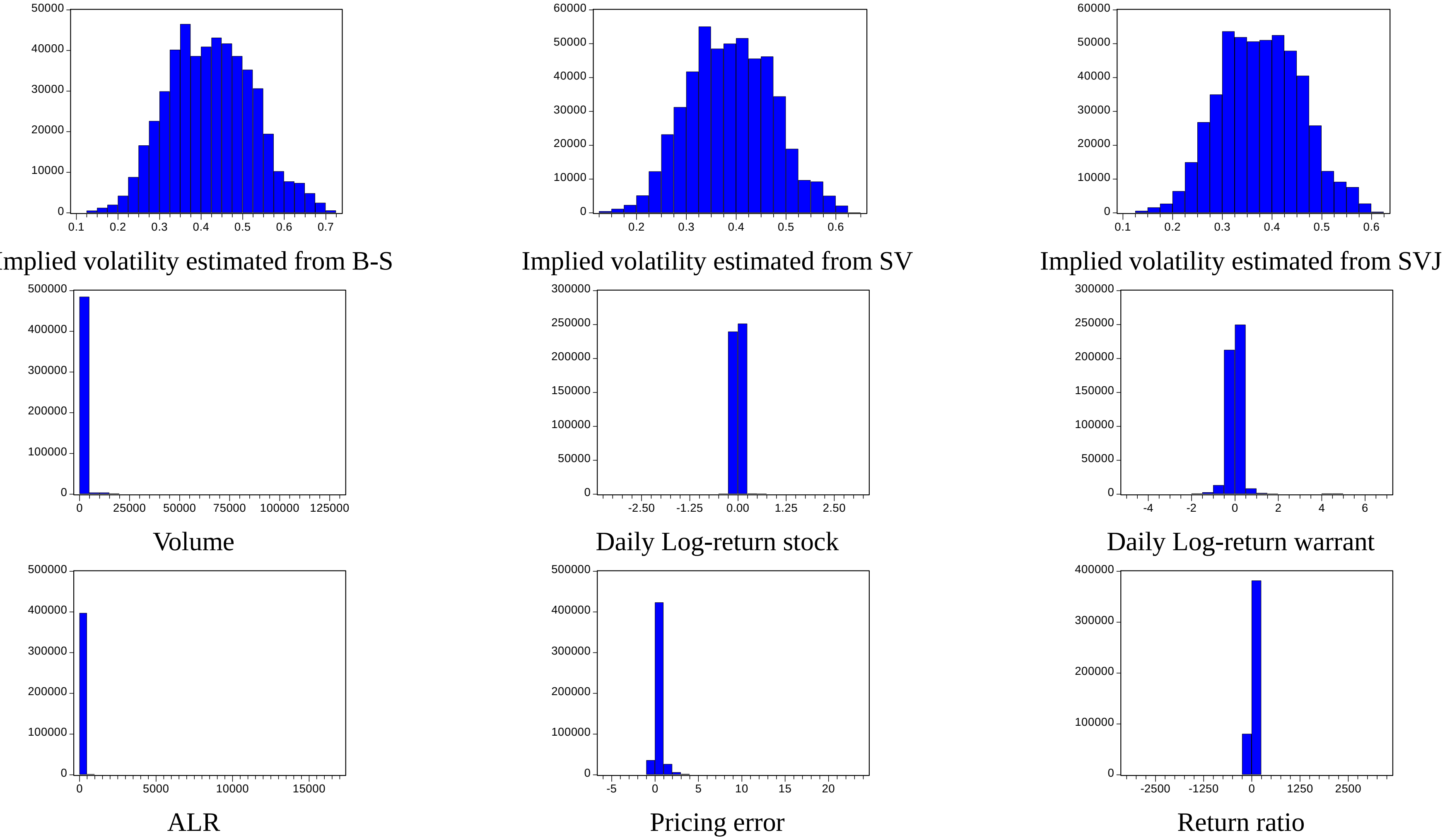
Industry	Const. Term	β_1	β_2	β_3	β_4	β_5
11 Cement	-0.019	0.012	0.007	-0.041	0.224***	0.461***
	(-1.105)	(1.345)	(1.031)	(-1.107)	(10.349)	(92.654)
12 Food	0.025	0.083***	-0.018***	-0.234***	0.173***	0.510***
	(1.341)	(14.003)	(-3.773)	(-6.000)	(11.241)	(133.462)
13 Plastic	0.103***	0.067***	0.044***	-0.492***	0.082***	0.541***
	(13.920)	(13.084)	(12.496)	(-29.715)	(7.075)	(206.506)
14 Textile	0.062***	0.012*	-0.048***	-0.169***	0.231***	0.501***
	(3.701)	(1.654)	(-9.601)	(-4.702)	(13.685)	(131.867)
15 Electric Machinery	0.062***	0.032***	0.052***	-0.255***	0.236***	0.465***
	(5.617)	(5.293)	(13.825)	(-9.646)	(19.375)	(128.038)
16 Electrical & Cable	-0.015	-0.022***	-0.003	0.033	0.031***	0.620***
	(-1.139)	(-4.353)	(-0.831)	(1.035)	(3.060)	(154.068)
17 Chemical Industry	0.106***	0.000	0.021***	-0.312***	0.171***	0.468***
	(10.946)	(-0.057)	(4.772)	(-16.713)	(13.098)	(171.073)
19 Paper & Pulp	-0.062***	-0.070***	0.040***	-0.004	0.261***	0.503***
	(-2.693)	(-4.849)	(5.888)	(-0.073)	(11.669)	(60.754)
20 Iron & Steel	0.008	0.065***	0.036***	-0.220***	0.118***	0.489***
	(1.277)	(19.897)	(15.254)	(-14.757)	(18.197)	(249.725)
21 Rubber	0.081***	0.019***	0.018***	-0.294***	0.214***	0.484***
	(4.980)	(2.864)	(3.684)	(-8.475)	(15.260)	(146.640)
22 Automobile	0.172***	0.098***	0.002	-0.544***	0.105***	0.568***
	(16.201)	(15.022)	(0.385)	(-21.264)	(8.037)	(156.837)
23, 24 Electronic Parts/ Semiconductor	0.077***	0.057***	0.038***	-0.286***	0.200***	0.403***
	(17.608)	(24.736)	(23.271)	(-31.551)	(42.407)	(443.111)
25 Building Material & Construction	0.130***	0.090***	0.002	-0.358***	0.109***	0.528***
	(8.397)	(15.363)	(0.441)	(-12.408)	(7.546)	(118.241)
26 Shipping & Transportation	0.108***	0.065***	-0.013***	-0.307***	0.207***	0.481***
	(14.665)	(13.519)	(-3.906)	(-21.196)	(21.470)	(162.938)
27 Tourism	-0.032***	0.053***	0.026***	0.032	0.165***	0.383***
	(-2.761)	(8.535)	(5.340)	(1.433)	(12.999)	(93.869)
28 Financial & Insurance	0.188***	0.019***	-0.014***	-0.584***	0.163***	0.593***
	(45.240)	(7.948)	(-7.772)	(-60.985)	(34.478)	(387.643)
29 Trading & Consumers Goods	-0.235***	0.129***	-0.015	0.270***	0.154***	0.537***
	(-6.810)	(9.115)	(-1.288)	(4.361)	(4.376)	(57.032)

Table 5. Decomposing Warrants Pricing Errors by Using Theoretical Pricing, Contract-Specific Characteristics, and Issuers-Specifications

Regression model is, $e_{i,t} = \beta_0 + \beta_1 CR_{i,t} + \beta_2 \tau_{i,t} + \beta_3 IV_{i,t} + \beta_4 Volume_{i,t} + \beta_5 Mony_{i,t} + \beta_6 ALR_{i,t} + \beta_7 (\ln r_{C_{i,t}} / \ln r_{S_{i,t}}) + \varepsilon_{i,t}$. The subscript i and t represent the i^{th} warrant on date t. $CR_{i,t}$, is a dummy variable of the credit rating of the issuer. If the credit rating is less than the A class, then the value is equal 1, otherwise the value of the dummy is 0. . $IV_{i,}$ is the implied volatility estimated from the three option pricing models, B-S, SV and SVJ; $Volume_{i,t}$ is the trading volume in terms of 10 thousand NTD. Two contract-specific variables, $Mony_{i,t}$ and $\tau_{i,t}$, measured in one hundred trading days, are the moneyness, defined as $S_{i,t}/K_i$ for the call warrant, and the remaining time to expiration for the i^{th} warrant in day t, respectively. The variable $ALR_{i,t}$, which is on one thousand units (NTD), to investigate functions of liquidity provider of the issuers after the warrants are listed to trade. The independent variable, $ALR_{i,t}$, is the daily liquidity ratio of a warrant and we plan to use well-popular measure used in market microstructure literatures, Amivest Liquidity Ratio, in terms of percentage, on daily return of the warrant to underlying stock. And ln $r_{Ci,t}$/ ln$r_{Si,t}$ which is used to investigate whether issuer manipulates the price of the warrants or not, is the ration of the nature-log daily return of i^{th} the warrants and underlying stock, respectively, on date t.

Pricing Errors Source of Pricing Errors from Alternative Models	Constant Term	Dummy for Credit Rating of Issuers	Time to Maturity of Warrants	Implied Volatility	Trading Volume	Moneyness	Amivest Liquidity Ratio	Ratio on Returns of Warrant to Stock
Black & Scholes (1973)	0.0905*** (27.80)	0.0632*** (36.60)	0.0446*** (34.56)	-0.3643*** (-55.03)	0.1962*** (58.99)	0.4224*** (529.66)	-0.1514*** (-22.88)	-0.0450*** (-2.53)
SV Heston (1993)	0.1084*** (30.81)	0.0632*** (36.61)	0.0445*** (34.56)	-0.4427*** (-55.46)	0.1962*** (58.98)	0.4224*** (529.74)	-0.1514*** (-22.88)	-0.0452*** (-2.54)
SVJ Bates (1996)	0.1084*** (30.81)	0.0632*** (36.61)	0.0445*** (34.56)	-0.4563*** (-55.46)	0.1962*** (58.98)	0.4224*** (529.74)	-0.1514*** (-22.88)	-0.0452*** (-2.54)

Figure 1. Distribution of dependent variables



Appendix 1

Heston (1993) asserted that the correlation between underlying asset returns and its volatility affects the skewness and leptokurtosis of the distribution of the underlying asset returns. The volatility is specified to follow an Ornstein-Uhlenbeck mean reverting process below:

$$dS(t) = \mu S(t)dt + \sqrt{V(t)}S(t)dz_S(t), \tag{A.1}$$

$$dV(t) = \kappa(\theta - V(t))dt + \sigma_V \sqrt{V(t)}dz_V(t), \tag{A.2}$$

where μ, which are known and assumed to be constant, represents the difference between instantaneous domestic risk-free interest rare r, and foreign one, r^*. $dz_S(t)$ and $dz_V(t)$ are Wiener processes with instantaneous correlation ρ, i.e., $corr\left(dz_S(t), dz_V(t)\right) = \rho dt$. The major difference between the model of Hull and White (1987) and the model of Heston (1993) is the specification of the correlation, ρ. The instantaneous variance $V(t)$ follows a square-root process proposed by Cox, Ingersoll and Ross (1985). The dynamic process, $dV(t)$, follows a mean-reverting process with long term mean, θ, mean reversion speed, κ, and volatility of volatility, σ_V.

Following the risk-neutral pricing probabilities derived by Cox, Ingersoll, and Ross (1985), Equation (A.2) can be rewritten as:

$$dV(t) = \kappa^*(\theta^* - V(t))dt + \sigma_V \sqrt{V(t)}dz_V(t), \tag{A.3}$$

where $\kappa^* = \kappa + \lambda$, $\theta^* = \dfrac{\kappa\theta}{\kappa + \lambda}$, and λ is the risk premium parameter compensated for the volatility risk from σ_V. The instantaneous risk-neutral variance process $V(t)$ drifts toward a long-run mean of θ^*, with the mean-reversion speed dominated by κ^*.

In general, if the risk-neutral probability density function of a future security's price is $f(S_T)$, the exercise price is *K*, the time to maturity is $\tau = T - t$, and the price of a European call option can be written as,

$$C = e^{-r\tau}\int_K^\infty (S_\tau - K) f(S_\tau)dS_\tau. \tag{A.4}$$

Heston (1993) derived the density function of *S* satisfying Equations (A.2) and (A.4) by inverting the Fourier transform for the convolution of the lognormal density of S_T conditional on the average variance and the density of average variance. The derivation relies on properties of the conditional distribution and involves numerical integration of the characteristic function of the probability process. The European call option on currency follows:

$$\begin{aligned} C &= e^{-r\tau} E^{*} \max(S_{\tau} - K, 0) \\ &= e^{-r\tau} \left[\int_{X}^{\infty} (S_{\tau} - K) f^{*}(S_{\tau}) dS_{\tau} \right] \\ &= SP_{1} - Ke^{-r_f \tau} P_{2} \end{aligned} \tag{A.5}$$

C, S, and *K* have the same meaning in the Black-Scholes model. In order to get a closed-form solution, Heston (1993) used the Fourier transformation and derived the probability density function P_j :[2]

$$P_j(x, v, t; \ln[K]) = \frac{1}{2} + \frac{1}{\pi} \int_0^{\infty} \mathrm{Re}\left[\frac{e(-i\varphi \ln(K)) f_j(x, v, t; \varphi)}{i\varphi} \right] d\varphi, \tag{A.6}$$

where *j*=1, 2, Re means the real part of the square bracket, $i = \sqrt{-1}$, $f_j(x, v, t; \varphi)$ represents the characteristic functions of the conditional probability P_j.

$$P_j = \frac{1}{2} + \frac{1}{\pi} \int_0^{\infty} \mathrm{Re}\left[\frac{\exp\left(-i\varphi \ln(K)\right) \cdot f_j}{i\varphi} \right] d\varphi, \quad j = 1, 2 \tag{A.7}$$

where f_j, $j = 1, 2$ is the characteristic function of parameters set, $\varphi = \{\kappa^{*}, \theta^{*}, \sigma_v, \rho\}$.

Under the risk-neutral measure, Bates (1996a) proposed a model which combined the concept of stochastic volatility (Heston, 1993) to catch the "skewness premium" with jumps process (Merton, 1976) to price the possibility of the jump risk in foreign currency price dynamics.

$$dS(t) = \mu_J S(t)dt + \sqrt{V(t)} S(t) dz_S(t) + dz_J(t), \tag{A.8}$$

$$dV(t) = (\alpha - \beta^{*} V(t))dt + \sigma_V \sqrt{V(t)} dz_V(t), \tag{A.9}$$

where μ_J represents instantaneous risk-free interest rare, in Bates' jump model, and $corr\left(dz_S(t), dz_V(t)\right) = \rho_J dt$.

As in (11) $dz_J(t)$, a random jump process with a compound Poisson process, $dq(t)$, with intensity λ, and

$$dq(t) = \begin{cases} 0 & \text{with probability } 1\text{-}\lambda dt \\ 1 & \text{with probability } \quad \lambda dt \end{cases}, \tag{A.10}$$

with a lognormal distribution of percentage jump sizes, $J(t)$ which is lognormally, identically, and independently distributed over time, with unconditional mean jump size, μ_J. That is,

$$\log\left(1+J(t)\right) \sim N\left(\log(1+\mu_J)-\tfrac{1}{2}(\sigma_V^J)^2,\ (\sigma_V^J)^2\right), \tag{A.11}$$

where $q(t)$ and $J(t)$ are uncorrelated with each other or with $z_s(t)$, $z_V(t)$, and $J(t) \sim N(\mu_J, (\sigma_V^J)^2)$. We reset a mean-reverting process as like in Heston (1993) model and add the jump component in the return process, for the sake of consistency for testing the performance between SV and SVJ model. From equation (A8), (A9), and (A11),

$$dS(t) = \mu S(t)dt + \sqrt{V(t)}S(t)dz_S(t) + \left(J(t)-1\right)S(t)dq(t). \tag{A.12}$$

The random walk in logs form follows from (A.12):

$$d\log(S(t)) = (\mu-\lambda\mu_J)dt + \sqrt{V(t)}dz_S(t) + \log J(t)dq(t), \tag{A.13}$$

or,

$$\frac{dS(t)}{S(t)} = (\mu-\lambda\mu_J)dt + \sqrt{V(t)}dz_S(t) + J(t)dq(t). \tag{A.14}$$

In sake of consistence on judging pricing performance between stochastic volatility model and jumps in mean process with stochastic volatility model, we follow Bakshi, Cao and Chen (1997) used the following mean-reverting volatility setting to get the characteristic function of parameters set

$$dV(t) = \kappa_J^*(\theta_J^* - V(t))dt + \sigma_J\sqrt{V(t)}dz_V(t). \tag{A.15}$$

Jump model is also can be used the Fourier transformation and be derived the probability density function P_j:

$$P_j(x,v,t;\ln[K]) = \frac{1}{2} + \frac{1}{\pi}\int_0^\infty \mathrm{Re}\left[\frac{e(-i\Phi\ln(K))f_j(x,v,t;\Phi)}{i\Phi}\right]d\Phi, \tag{A.16}$$

where j=1, 2, Re means the real part of the square bracket, $f_j(x,v,t;\Phi)$ represents the characteristic functions of the conditional probability P_j.

$$P_j = \frac{1}{2} + \frac{1}{\pi}\int_0^{\infty} \text{Re}\left[\frac{\exp\left(-i\Phi\ln(K)\right)\cdot f_j}{i\Phi}\right] d\Phi \, , \qquad \text{(A.17)}$$

$$j = 1, 2$$

where f_j, is characteristic function of parameters set, $\Phi = \{\lambda, \mu_J, \sigma_v^J, \kappa_J^*, \theta_J^*, \sigma_v, \rho_J\}$.

Skewness in the distribution is controlled by either the correlation ρ or the mean jump μ_J; whereas the amount of kurtosis is regulated by either the volatility diffusion parameter σ_V or the magnitude and variability of the jump component, σ_V^J. But the ability of the diffusion component, $V(t)$ to generate enough short-run negative skewness or excess kurtosis is limited, as $V(t)$ can only follow a continuous sample path. On the other hand, the discontinuous jump process can internalize any skewness and kurtosis level even in the short run, especially when λ, μ_J and σ_V^J are substantial. Therefore, these two forces capture different aspects of return distributions.

Furthermore, the third risk factor could earn a premium is provided from the viewpoints from Cox, Ingersoll, and Ross (1985) who treated the discount factor as a stochastic interest rate. For example, Bailey and Stulz (1989) and Bossaerts and Hillion (1993) priced stock index and stock options using the Cox, Ingersoll, and Ross (1985) general equilibrium production economy, which implies instantaneous conditional variances and interest rates are proportional and follow the square root process. On the other hand, Hull and White (1988), Heston (1993), and Bates (1996a) priced options under the more tractable assumption of constant interest rates. Since the results, proposed by Rubinstein (1985) Scott (1993), Bates(1996a), and Bakshi, Cao and Chen (1997), show that interest rate volatility has little impact on short-term-maturity option prices, the latter assumption of constant domestic and foreign interest rates will be maintained in this study.

Appendix 2

Presently, values of volatility in B-S model and other parameters of the mean and volatility process implicit in SV and SVJ models are need to be estimated, before the theoretical premium of warrant are obtained. We firstly show the algorithm to obtain the volatility estimates and then illustrate that of parameters in SV and SVJ models as follows.

Step1. The history volatility are estimated from three methods, standard deviation of the return on underlying stocks and GARCH-families volatility models proposed by Engle (1982) and extended by Bollerslev (1986).

Step2. To get the parameters implicit in the SV and SVJ options pricing models, we all sample traded from 1999 to 2007 and use equally-weighted sum of square errors in day t for the same underlying security for all warrants traded in the market to back out the implicated parameters in return and volatility processes. Then we use the estimated values as inputs parameters to the SV and SVJ models to obtain the theoretical price of a warrant.

Step3. Since the estimated values of volatility and parameters in dynamic return and volatility process of SV and SVJ models could have the small sample biases as the warrant near the maturity date, we will use a non-parametric bootstrapping approach to overcome the low frequency data problem by drawing samples at random with replacement and by performed 100,000 times to obtain a smooth time-matching volatility distribution.

Step4. We match the time to maturity of the estimates of volatility and those of parameters implicit in SV and SVJ models from *Step1* to *Step3*, for example, one warrant i has the remaining time to expiration, τ, on the underlying stock j in day t, we use the estimated values of historical volatility on the duration t-τ as the input values to calculate the theoretical warrant price. The similar approach is applied to back out the parameters in SV and SVJ as inputs in the models.

According to the time series pricing errors estimated from three alternative models for each warrants, we plan to arrange the sample into subgroups depending on a suitable and reasonable criteria.