The Shape of Option Implied Volatility：A Study Based on Market Net Demand Pressure

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The Shape of Option Implied Volatility —A Study Based on Market Net Demand Pressure

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I. Forward

Many studies have found that most curves of option implied volatility resemble the profile of a "smile", however, this conflicts with the assumption of Black-Scholes (hereinafter referred to as the B-S) option pricing model. This phenomenon becomes the well-known "option pricing puzzle". Then a large amount of literature focuses on how to explain the "implied volatility smile" and what information content such a shape implies (Zhenlong Zheng, 2009; Yizhou Huang, Zhenlong Zheng, 2009).

To explain the shape of option implied volatility, researchers start with releasing the assumptions of B-S's option pricing model and gradually developing various option pricing models that are closer to the practical process of asset price change (for example, Hull and white (1987) put forward the Stochastic Volatility (SV) model, Merton (1976) put forward the Jump Diffusion (JD) model and Bates (1996) put forward the Stochastic Volatility and Random Jump (SVJ) Model). However, this cannot fully capture the empirical properties of option prices yet.

Then can the shape of option implied volatility be explained by market factors other than those related to no-arbitrage theory? No-arbitrage theory suggests that when option price can be replicated perfectly, option is redundant. There exists a no-arbitrage equilibrium. Once the equilibrium is broken, arbitrageurs will enter into the market and finally push the option price back to the no-arbitrage equilibrium. In reality, however, arbitrage fails to go smoothly since it is restrained by many practical facts (for example, Liu and Longstaff (2004), Brunnermeier and Pedersen (2009), Carole et al. (2010) have conducted studies on such restraints). Then we come to realize that option price is practically affected by so many factors, it actually submits to a no-arbitrage price range. Within the no-arbitrage price range, option price fluctuates under effects of certain market factors.

Among all the efforts, the attempt to explain the implied volatility smile by analyzing the risk compensations of market makers, the intermediary of the option market, is receiving more and more attention. The reason is that the option market of every country, sophisticated or new-born, mostly adopts the market maker system for trading. Under the market-maker system, market-makers act both as a quote offer of option price and a liquidity provider by taking the other side of market investors (non-market makers).[①] In case of net trading demand pressure resulting from unequal long and short volumes, market makers tend to use their capital to hold a certain net position, which on the one hand meets trading demand on the market but on the other hand exposes market makers to certain risks. So market markers reasonably imply their desired risk compensations in their quotation of option which to some extend changes the shape of the implied volatility curves.

It is commonly believed that risks posed by net option positions to market makers stem from three aspects: first, market makers are faced with certain hedging risks due to practical factors like impossibility of trading continuously, stochastic volatility, jumps in the underlying; secondly, constrained by capital, market makers may change their attitude towards risk-taking due to profits or losses of their own accounts and this will ultimately affect their demanded risk compensations; thirdly, traders on the option market are generally believed to be informed traders and market makers, out of concerns of asymmetric information risks, will demand certain risk compensations.

However, after consulting relevant literatures, we’ve found that most studies are with following limitations when studying option pricing under the market-maker system:

1. There is no literature conducting an overall study of the shape of implied volatility by integrating hedging risks, capital constrained risks and asymmetric information risks.

2. As for theoretical models, these literatures have failed to offer accurate model expressions of how option trading demand pressure causes market makers to adjust their quotations. They express ambiguous comprehensions on what kinds of option trading demand pressure will affect option quotation and how. For example, Dennis and Mayhew (2002) turn to volume ratio of put options to call options, while Bollen and Whaley (2004, hereinafter referred to as BW) turn to net purchase volumes and believe that only own option net purchase has remarkable effects on its price.

3. Obtaining actual market makers’ net positions data is difficult. As a result, most literatures (Chan et al. (2004, 2006), Shiu et.al (2010)) tend to apply certain kinds of methods to build variables to stand for option net trading demand pressure faced by market markers. However, it remains to be seen whether such special variables can actually represent option net trading demand pressure faced by market makers.

4. When studying the relationship between net demand pressure and implied volatility smile, many literatures try to directly build a regression equation between option trading demand pressure and option price or implied volatility. The accuracy of this attempt remains to be seen, for the implied volatility back-calculated from market price contains not only information of market marker’s risk compensation but information of pricing factors of traditional option pricing models (such as stochastic volatility and jump). Therefore, incorporating option trading demand pressure and implied volatility directly into a regression equation will eventually mix together multi-information and makes it difficult to specify and tell exactly what is affected by market trading demand pressure.

In view of the deficiency of theoretical modeling, Garleanu, Pedersen and Poteshman (2009,

[①] ”Market investors” hereinafter all refer to market investors other than market makers.

hereinafter referred to as GPP) put forward an option pricing model based on net market demand pressure. This model takes the maximization of utility function of representative market makers as objective function. Also, it separately elicits the function representation of net demand pressure to the level and slope of implied volatility in the presence of three cases of imperfect hedging in reality, such as discontinuous trading, stochastic volatility, jumps in the underlying. It can be said that this model proposed by GPP (2009) is another breakthrough of analyzing option price and the shape of option implied volatility in the micro-structure of the option market after the classical success of BW (2004) introducing the imbalanced market demand and supply to option price analysis.

Though GPP (2009) has successfully built the model of implied volatility adjustment incurred by market net demand pressure, their study is obviously defective in its all-sidedness and empirical research:

First of all, there is a lack of studies on asymmetric information risks taken by market makers. GPP (2009) mainly starts with the inventory risks faced by market makers and proceeds to their impact on the shape of the implied volatility curve. However, there are a number of studies indicating that asymmetric information risk is another major risk market makers have to take and the implied volatility curve back-calculated by market price most probably contains the influence of asymmetric information risk.

Then there comes the problem of approach to empirical research. A fair part of the theoretical option pricing parameters and parameters intended to describe the dynamic process of the underlying in the real world, as used by GPP (2009), are directly quoted from optimum parameters of other articles, which brings about the matching problem of data sample interval and models used. Besides that, when studying the impact of option net demand pressure on adjustment items of the level of implied volatility, GPP approaches to building variables for such adjustment items by subtracting one volatility from another under a different measurement, which may involving risk premium information of volatility. This ultimately will make the empirical result unreliable.

The abovementioned deficiency has prompted our efforts in this paper. First, to root out impact on our research from information of the characteristics of the price dynastic process of underlying assets, as implied in the curve of implied volatility, we've improved the empirical approach taken by GPP (2009) and have chosen the SVJ option pricing model of Bates (2006). Then we proceed to sorting out the high frequency data of weighted index options of Taiwan Stock Exchange (referred to as TAIEX) Options to obtain data of market net demand pressure. This TAIEX Options' high-frequency data contain a indicator that can directly identify investors and their trading tendency, so this helps us directly obtain the market net demand pressure of each option market makers are faced with, which gives more accuracy to net demand pressure data compared with most of the previous documents. Then, using data of daily net positions of market investors obtained from original data, we go on to make a detailed analysis of net position situations of TAIEX Options Market right during the financial crisis and, taking daily net position data as indexes of market net demand pressure, we've also analyzed influences on the shape of implied volatility from hedging risks and capital constrain risks. In the end, we use data of net daily volumes of market investors as obtained from the original data to study the information content of market trade and analyze the impact on the shape of implied volatility from the angle of asymmetric information risk.

This paper has chosen the TAIEX Options as the object of research for the following three reasons: 1. The huge volumes of TAIEX Options suggest that TAIEX Options market is an active market; 2. The TAIEX Options market has been successfully implementing the market-maker system and the new market makers' joining since 2005 has contributed to the rapid expansion of volumes of TAIEX Options; meanwhile, market makers are claiming increasingly important positions in trading with bigger and bigger trading proportion, with their quotation greatly affecting the market price; 3. With a longer history, the financial derivative market of Taiwan is more sophisticated than that in mainland China and the introduction of index option products has obtained tremendous recognition; besides, the common history and cultures shared by people in Taiwan and the mainland indicate many similarities in investment psychology and behavior, so studying the options market in Taiwan will offer certain market experience and reference value to the future development of index option products in mainland China.

Apart from the foreword, this paper consists of four parts: part II will introduce the option pricing model based on market net demand pressure, which shows the impact of market net demand pressure on the level and slope of implied volatility in the presence of discrete trading, stochastic volatility, jumps in the underlying; part III introduces sample data and goes on to define some of the variables (adjustment items of the level and slope of implied volatility, weighted sum of market net demand pressure); part IV is empirical research intended to extract information implied by the shape of the implied volatility respectively from market makers' hedging risk, capital constrain risk and asymmetric information risk; part V comes to the conclusion.

II. Option pricing model based on market net demand pressure

Put forward by GPP (2009), this model assumes that in an economy of unlimited period of discrete time there exists a risk-free asset and a risk asset, the latter being stock index; the per period rate of return on the risk-free assts is R_f ; at time t, price of the stock index is S_t , its dividend being D_t , both S_t and D_t being exogenous; the abnormal return of stock index is $R_t^e = (S_t + D_t)/S_{t-1} - R_f$, with distribution of future rate expressed by Markov State variable X_t .

In this economy, this stock index is taken as an underlying security and a series of index options based on this stock index will be taken in, with the price of index options endogenously determined. Index options of different characteristics are to be marked by $i \in I$. With I standing for the set of all index options in trading, i therefore differentiate information like the maturity, executive price, call or put of different index options. The index option payoff is a function based on X_t , price vector marked as $p_t = (p_t^i)_{i \in I_t}$.

Suppose the index option market has a representative market maker and its utility function takes the form of Constant Absolute-Risk Aversion (CARA):

$$u(\mathrm{C}) = -\frac{1}{\gamma} e^{-\gamma \mathrm{C}} \tag{1}$$

where γ stands for the risk aversion coefficient. Then the sum of remaining utility of the market maker is:

$$U(C_t, C_{t+1}, \ldots\ldots) = E_t\left[\sum_{v=t}^{\infty} \rho^{v-t} u(C_v)\right] \tag{2}$$

ρ stands for the discount factor and the wealth evolves as:

$$W_{t+1} = (W_t - C_t)R_f + q_t(p_{t+1} - R_f p_t) + \theta_t R_{t+1}^e \tag{3}$$

It can be told that at each time t, wealth of the market maker is put into four aspects: one part for consumption C_t, one part for investment in stock index θ_t, another part for holding $q_t = (q_t^i)_{i \in I_t}$ of net index option position and the remaining part for investing in risk-free assets.

The concept corresponding to the daily net position of market maker is the daily net position of market investors, which reflects the daily accumulated value of imbalanced supply and demand of market investors. Here it is defined as "market net demand pressure", expressed as $d_t = (d_t^i)_{i \in I_t}$ where d_t stands for the exogenous variable[②] and the derivatives market clearing: $q + d = 0$.

By bringing in value function $J(W;t,X)$ which is based on wealth W, state variable X and time t, we build the Bellman equation of the value function:

$$J(W_t;t,X_t) = \max_{C_t, q_t, \theta_t}\left\{-\frac{1}{\gamma} e^{-\gamma C_t} + \rho E_t\left[J(W_{t+1};t+1,X_{t+1})\right]\right\} \tag{4}$$

Then the optimization of asset allocation of the market maker can be expressed as C_t, q_t, θ_t solving the following maximization problem:

$$\max_{C_t, q_t, \theta_t} \quad -\frac{1}{\gamma} e^{-\gamma C_t} + \rho E_t\left[J(W_{t+1};t+1,X_{t+1})\right] \tag{5}$$

$$s.t. \quad W_{t+1} = (W_t - C_t)R_f + q_t(p_{t+1} - R_f p_t) + \theta_t R_{t+1}^e$$

[②] In reality, market investors trade their options out of a variety of trading motives, such as portfolio insurance, behavior factors of individual investors and asset allocation of institutional investors. These models do not intend to study the trading motive behind the trading volumes. They are supposed to be exogenous variables.

When the value function takes the following form:

$$J(W_t;t,X_t) = -\frac{1}{k}e^{-k(W_t+G_t(d_t,X_t))}, \quad k = \frac{\gamma(R_f-1)}{R_f} \tag{6}$$

We can deduce[③] that the derivative price p and hedging amount θ meet the following relationship which, when expressed in the framework of stochastic discount factor, is:

$$p_t = E_t\left(m_{t+1}^d p_{t+1}\right) = \frac{1}{R_f}E_t^d\left(p_{t+1}\right) \tag{7}$$

$$0 = E_t\left(m_{t+1}^d R_{t+1}^e\right) = \frac{1}{R_f}E_t^d\left(R_{t+1}^e\right) \tag{8}$$

where the stochastic discount factor m_{t+1}^d is a function based on net demand pressure:

$$m_{t+1}^d = \frac{e^{-k\left(\theta_t R_{t+1}^e + q_t p_{t+1} + G_{t+1}\right)}}{R_f E_t\left[e^{-k\left(\theta_t R_{t+1}^e + q_t p_{t+1} + G_{t+1}\right)}\right]} = \frac{e^{-k\left(\theta_t R_{t+1}^e - d_t p_{t+1} + G_{t+1}\right)}}{R_f E_t\left[e^{-k\left(\theta_t R_{t+1}^e - d_t p_{t+1} + G_{t+1}\right)}\right]} \tag{9}$$

where $\theta_t R_{t+1}^e + q_t p_{t+1}$ stands for the portion where the market maker cannot hedge perfectly and this expression complies with economic intuition: the bigger position with failed perfect hedging, the bigger risks faced by market makers, meanwhile the higher return rate required and the smaller stochastic discount factor.

The above results lead us to the discovery that the composite effects of the net demand pressure of all options on a certain option price is the sum of the effects of all individual net demand pressure, more specifically, the total of the sum of each option's net demand pressure multiplied by price-influencing factor $\frac{\partial p_t^i}{\partial d_t^j}$ implied in the model. Then, we come to the following theory:

Theorem 1: The first order sensitivity of option i price to the net demand of option j is proportional to the covariance between the hedging differences of the two and the market maker's risk aversion coefficient.

$$\frac{\partial \theta_t}{\partial q_t^j} = -\frac{\text{cov}_t^d\left(p_{t+1}^j, R_{t+1}^e\right)}{\text{var}_t^d\left(R_{t+1}^e\right)} \tag{10}$$

$$\frac{\partial p_t^i}{\partial d_t^j} = \gamma\left(R_f - 1\right)\text{cov}_t^d\left[\overline{p}_{t+1}^j \overline{p}_{t+1}^i\right] \tag{11}$$

[③] See GPP(2009) for detailed model derivation.

where， $$\overline{p}_{t+1}^{k}=R_f^{-1}\left(p_{t+1}^{k}-R_f p_t^{k}-\frac{\mathrm{cov}_t^d\left(p_{t+1}^{k},R_{t+1}^{e}\right)}{\mathrm{var}_t^d\left(R_{t+1}^{e}\right)}R_{t+1}^{e}\right) \quad (12)$$

In the above theorem, $\overline{p}_{t+1}^{k}$ stands for the portion of index option k with failed perfect hedging, i.e. by hedging with the optimum hedging ratio $\mathrm{cov}_t^d\left(p_{t+1}^{k},R_{t+1}^{e}\right)\Big/\mathrm{var}_t^d\left(R_{t+1}^{e}\right)$, the unhedgeable part discounted with risk-free interest rate. Similarly, the theorem suggests that with the optimized asset allocation of the market maker, the amount invested into underlying index will minimize risks with asset portfolio. The net demand of all index options on the market will exert certain impact on the price of an individual index option and such impact is transmitted in two parts: 1. The part common to individual option on the market, i.e. the risk coefficient of the market maker and the risk-free interest rate on the market; 2. The part unique to individual option, i.e. the covariance of unhedgeable part between options.

After obtaining the first order influence of net demand pressure on the option price, we can get the composite influence of the net demand pressure of all options on option price and the option price express as:

$$p_t \approx p_t\left(d_t=0\right)+\gamma\left(R_f-1\right)E_t^d\left(\overline{p}_{t+1}\overline{p}_{t+1}'\right)d_t \quad (13)$$

The above expression reveals the two parts that make up the price of index options: first, the portion free of influence from net demand pressure, which can be taken as the portion affected by the arbitrage free pricing relation of underlying assets; second, the portion of price adjustment influenced by net demand pressure. Similarly, the implied volatility is also influenced by these two factors. So when studying the shape of implied volatility, we will first remove the portion that is affected by the no-arbitrage relation of underlying assets from the implied volatility, which includes the influence from stochastic volatility and jump as attracting attention from most studies and then we proceed to the portion of the implied volatility that is affected by the net demand pressure.

Then based on the three causes that lead to imperfect hedging for market makers, discontinuous trading, jumps and stochastic volatility with the price of underlying assets, GPP (2009) deduced the specified expression of the first order sensitivity of option price to net demand pressure:

Table 1 Expressions of first order sensitivity of implied volatility to net demand pressure

Cause of imperfect hedge	Expressions of first order sensitivity of implied volatility to net demand pressure
discontinuous trading	$\frac{\partial\hat{\sigma}_t^i}{\partial d_t^j}=\frac{\gamma r\,\mathrm{var}_t((\Delta s^2))}{4}\frac{f_{ss}^i}{v^i}f_{ss}^j+0(\Delta_t^2)$
Stochastic volatility in the underlying	$\frac{\partial\hat{\sigma}_t^i}{\partial d_t^j}=\gamma r\,\mathrm{var}(\Delta\sigma)(\frac{1-e^{-\phi T}}{\phi T})\ f_{\sigma}^j+0(\Delta_t^2)$

Jumps in the underlying	$\frac{\partial \hat{\sigma}_t^i}{\partial d_t^j} = \frac{1}{v^i}\gamma r[(f_s^i s_t - \theta^i)(f_s^j s_t - \theta^j)\,\mathrm{var}_t(\Delta s) + \pi \Delta t E_t(\kappa^i \kappa^j)] + 0(\Delta_t^2)$

where Δt is hedging interval; $f^i = f^i(t, X_t)$ is the price of option i; $f_S^i = \partial f^i(t, X_t) / \partial S$; $f_{SS}^i = \partial^2 f^i(t, X_t) / \partial S^2$, $\Delta S = S_{t+1} - S_t$; jump density is π; the jump density of a period is $\pi \Delta t$; $\kappa^i = f^i(s_t + \eta) - f^i - \theta^i \eta$, is the unhedgeable risk in case of a jump size η; ϕ stands for the mean reversion of volatility.

We can discover from the above table that with discontinuous trading and stochastic volatility, the first order sensitivity of the price of option i to the net demand pressure j has nothing to do with the moneyness (Moneyness④) of option i; therefore net demand pressure affects only the level of implied volatility, not the slope; in the presence of jump, the first order sensitivity of the price of option i to the net demand pressure j has something to do with the moneyness of option i and now net demand pressure affects not only the level of implied volatility but the slope. Meanwhile, the risk aversion coefficient of the market maker also exerts effect on the first order sensitivity of option price to net demand pressure⑤. So during empirical tests, we will first remove the portions that are affected by the stochastic volatility and jump of underlying assets from the implied volatility before going on to the three specific cases of hedging risks, as well as the changes in risk attitudes due to profits and losses of market makers' account.

III. Sample data and variable definitions

i. Sample data

Data samples we've obtained are based on the high-frequency data of TAIEX Options from Jan. 2008 to Mar. 2009, 293 days in total. The "Identity" column tells the subject of trader, with code 56 suggesting the subject being a market maker; TXO in the "Commodity" column suggests the dealing being TAIEX Options; "Option" tells call option and put option; "Delivery time" tells the maturity month of the trading option; "Buy and sell" tells the direction of the dealing, "B" suggesting buy and "S" suggesting sell. Therefore, these data helps us accurately abstract daily net position data of market investors (or market makers).

Processing with MATLAB software has obtained the data of daily net volumes of each option:

1. Abstract transaction data of whose "Commodity" is TXO and "Identity" 56 and obtain the daily TAIEX Options high-frequency data traded by market makers;

2. As for daily high-frequency data of TAIEX Options of market makers, TAIEX Options of different clause will be sorted out by columns like "Option", "Delivery time", "Exercise price" and "Commodity" and buy "Volumes" will be subtracted from the sell "Volumes" of options of the

④ i.e. X / S, where X stands for exercise price and S the price of underlying assets.

⑤Although jump risk itself can result in volatility smile without the impact of net demand pressure, the presence of jump risk makes it possible for market net demand pressure to give a further effect on the implied volatility.

same clauses to get the daily net volumes of each option faced by market makers.

Then, the following process helps obtain daily data of market net position of each option:

1. According to types of option terms traded during the sample period, each net transaction will be classified to get an option trading matrix: The ordinate axis is classified by option terms and the cross axis is classified by option trading date. Contents of the matrix are net daily volumes of each option, i.e. the quantity of each option entering into the net position each day;

2. When calculating net position data of a certain option on a certain trading day, we sum up all net trading volumes of this option before this trading day.⑥

To get an intuitive understanding of market net position, we shall make statistics of call options and put options in different groups according to moneyness and maturity. Fig. 1 shows the trend diagram of the weighted index of Taiwan from Jan. 2008 to Mar. 2009, while Fig. 2-5 show changes in market net position of TAIEX Options from Jan. 2008 to Mar. 2009:

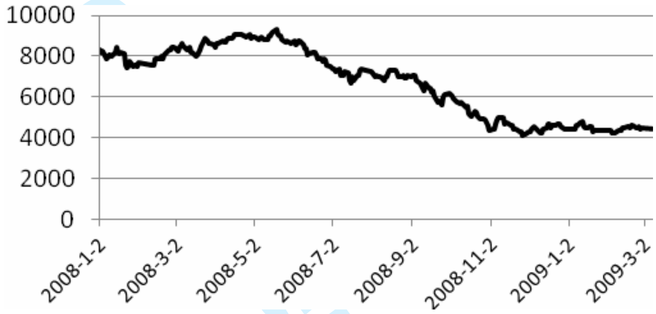
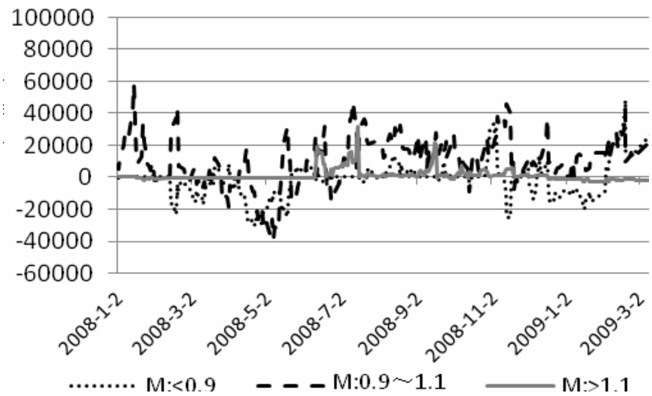


Fig. 1 Trend diagram of weighted index in Taiwan



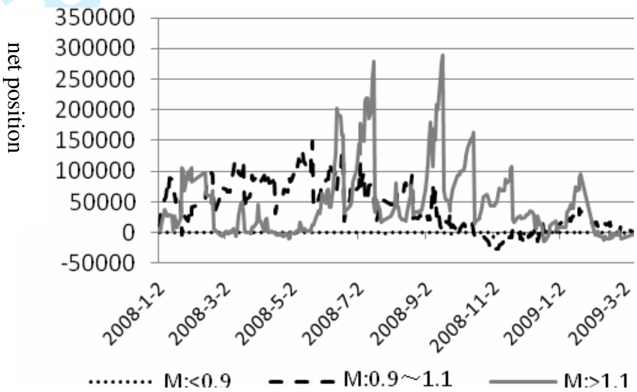


Fig. 2 Grouping of call option net position by moneyness **Grouping of put option net position by moneyness**

⑥Restricted by data sample reason, this paper supposes that the net option position before Jan. 2008 is 0. We believe that this assumption will not have too much impact on the net position data we will build. Because each day, TAIEX Options has 5 maturing contracts on the market for trading, the maturing month respectively being three continuous months from the current month and the two following continuous season months. However, those with active trading are only options with 0～45 days of remaining time, which accounts for over 95% of option volumes. Therefore, among those entering net position before Jan. 2008 are mainly options with 0～45 days of remaining time. Since these options will mature within a short period of time, they won't cause much impact on the option net position between Jan. 2008 and Mar. 2009.

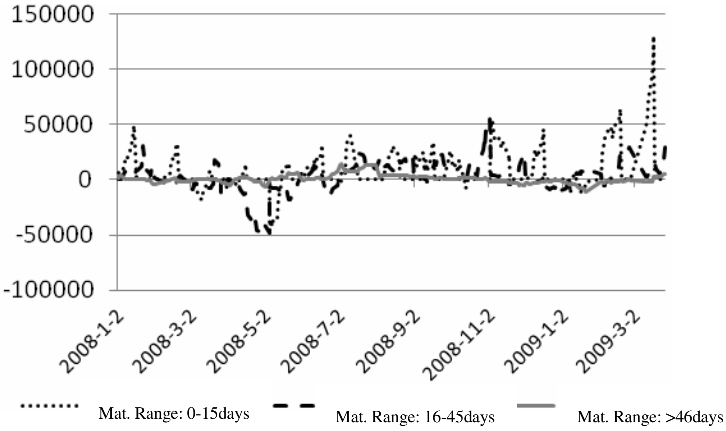


Fig.4 Grouping of call option net position by maturity

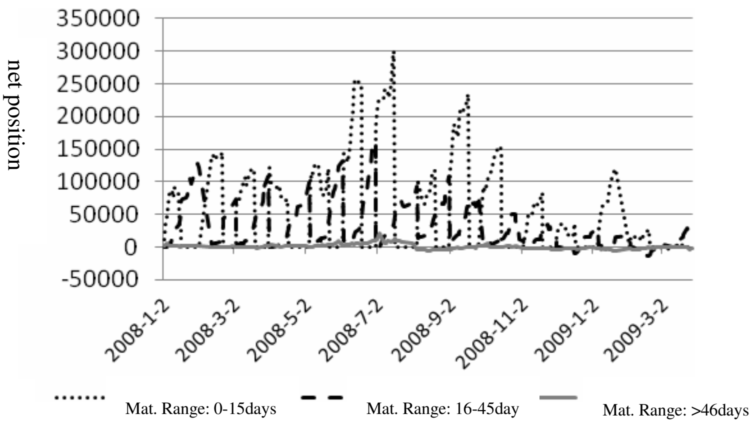


Fig.5 Grouping of put option net position by maturity

Comparison between call and put options in the above diagrams shows that the quantity of long net positions of put options held by the market investor is much bigger than that of long net positions of call potions; besides, since 2009, the position of put options tends to shrink while that of call positions tends to increase, indicating changes in TAIEX Options traders' prediction of the future trends of Taiwan index.

It can be told from the moneyless distribution of options in Fig. 2 and Fig. 3 that both call options and put options concentrated at ATM options (M: 0.9～1.1). From May 2008, however, put options began to focus on in-the-money options (M: >1.1), which might be explained by the decline in the market since 2008, causing the transfer of many out-of-money and ATM options to in-the-money put options while the market failed to close position for these options. During stable market operation, for example, from Jan. to May 2008 and from Nov. 2008 to Mar. 2009, position–holding of call options being negative or positive, indicating that long-short parties differ greatly. During the decline from May to Nov. 2008, market position holding of call options is positive, indicating that the market now tends to buy call options. During market decline, buying of call options is possibly caused by the expectation of market reversal: when market continues to decline, the worst is losing small amount of option value, but earnings will be rewarded once the market rebounds. The market always holds long positions for put options, which was possibly caused by special circumstances in 2008 and 2009. During 2008, when the financial crisis was in its prime, investors had increased risk aversion, which lead to remarkably increased demand for put options.

It can be told from Fig.4 and Fig. 5 that, under most circumstances, net option position on the market investors concentrates on two monthly contract types, 0-15 days and 16-45 days. Since July 2008, most 16-45 days contracts started to shift to 0-15 days contract, which reflected that option holders were becoming uncertain about prediction of long-term future trends.

ii. Variable definitions

Since we need to verify in our empirical research whether implied volatility is influenced by net demand pressure, we need to build the adjustment item of level and slope of implied volatility and the model weighted sum of net demand pressure. The adjustment item of the implied volatility level (slope) refers to the remaining part of the implied volatility level (slope) after removing factors like the stochastic volatility and jump of underlying assets; the weighted sum of net demand pressure, according to the conclusion reached by GPP (2009), will sum up the net demand pressure of all options on the market respectively in the presence of discontinuous trading, stochastic volatility and jump of the underlying assets.

1. Building the level and slop adjustment items of the implied volatility

Option market price is an antithesis of information. The curve of market implied volatility (hereinafter referred to as the '*IV_Market* ') back-calculated from the BS model, includes the composite information of non-net demand pressure, such as the stochastic volatility and jump of the option market. The stochastic volatility – jump option pricing model, however, has comprehensively taken into consideration the process of stochastic volatility and jump of underlying assets. Therefore, after pricing the options using the SVJ option pricing model, the theoretical implied volatility curve (hereinafter referred as the '*IV_SVJ*') back-calculated through the BS model can reflect the implied volatility curve in the presence of influence from the stochastic volatility and jump of underlying assets.

Therefore, after subtracting *IV_SVJ* from *IV_Market*, the remaining part can be used to study whether net demand pressure exerts impact on the implied volatility.

a. Selection of *IV_Market*

Data of *IV_Market* in this paper are the data of implied volatility of TAIEX Options with a remaining period of 1 month from Jan. 2, 2008 to March 27, 2009. This data comes from Bloomberg.

Moneyness includes seven types, namely 90%, 95%, 97.5%, 100%, 102.5%, 105 and 110%, so the total number of our data comes to 293 days * 7/day=2051. The reason why we choose Taiwan index options with only 1 month of remaining time is that the volume of such options are the most active and their price can best reflect market information.

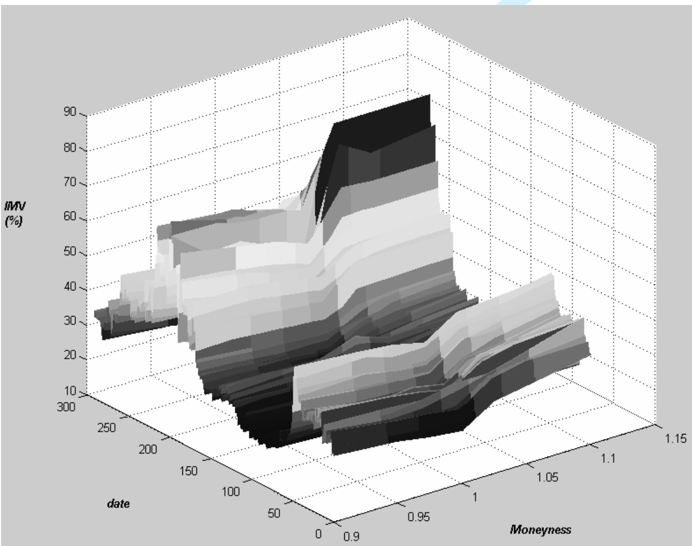


Fig. 6 market implied volatility of Taiex Options(1 month remaining)

Data source: Bloomberg

Fig. 6 shows that the market implied volatility of Taiex Options does resemble a smile. The implied volatility of ATM options tends to be lower than implied volatility of deep-the-money and deep-out-of-the-money options.

b. Acquisition of *IV_SVJ*

This paper has referred to the SVJ option pricing model of Bates (2006) to carry out theoretical pricing of TAIEX Options and then we obtain the surface *IV_SVJ* of the theoretical implied volatility.

By referring to the model of Bates (2006) and the Approximate Maximum Likelihood based on filter [7](hereinafter referred to as the 'AML-Filter'), this paper will first estimate the dynamitic process of spot index under actural measurement by using the daily closing price of Taiwan Index from July 29, 2005 to Jan. 17, 2011 to obtain the dynamic process parameters and the daily instantaneous volatility data of underlying assets.

Then the actual measurement parameters and instantaneous volatility data are taken into the SVJ option pricing formula to get the residual sum squared minimized:

$$\min\{\sum_{tao}\sum_{Moneyness}(Option\_market - Option\_SVJModel(\theta^*))^2\}$$

θ^* stand for risk neutral parameters of the SVJ option pricing model while tao stands for the remaining time of option.

We can estimate the risk neutral parameters of the SVJ option pricing model by conducting theoretical pricing of TAIEX Options under the SVJ model. Then the surface of *IV_SVJ* [8]of the theoretical implied volatility of the SVJ option pricing model can be back-calculated through the BS formula.

Then, subtracting *IV_SVJ* from *IV_Market* can produce the portion of the implied volatility curve that is influenced by market net demand pressure.

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[7]Limited by length of paper, specific procedures of AML-FILTER will not be described. Please refer to original paper of Bates (2006).

[8] Since risk neutral parameter can only be obtained through back-calculation of option market price calibration while option market price contains the information of market micro-structure, the surface of theoretical implied volatility obtained through this method therefore contains certain information of market micro-structure. This, however, won't affect empirical results. Because the surface of theoretical implied volatility obtained in this way contains information of market micro-structure which is the average information of market micro-structure during the sample period and the adjustment item of implied volatility obtained in this way still can reflect daily changes in market micro-structure.

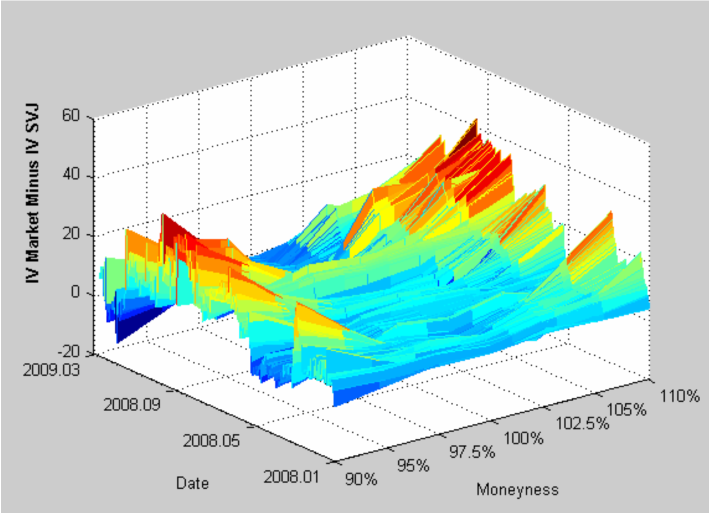

Fig. 7 *IV_Market* minus *IV_SVJ* (different moneyness and different observation date)

We can see from the above figure that under most circumstances, *IV_SVJ* is smaller than *IV_Market* and especially for deep-the-money and deep-out-of-the-money options, the SVJ option pricing model obviously underestimates.

c. Building level and slope adjustment items of the implied volatility

Putting *IV_Market* and *IV_SVJ* through following process produces the level and slope adjustment items of the implied volatility:

$$ExcessLevel = IV\_Market_{M=100\%} - IV\_SVJ_{M=100\%}$$

$$\begin{aligned} ExcessSlope &= Slope\_Market - Slope\_SVJ \\ &= \left(IV\_Market_{M=110\%} - IV\_Market_{M=100\%}\right) \\ &\quad - \left(IV\_SVJ_{M=110\%} - IV\_SVJ_{M=100\%}\right) \end{aligned}$$

Table 2 Descriptive statistics of level and slope adjustment items

	Even	Max	Min	Standard deviation	Skewness	Kurtosis	ADF
ExcessLevel	3.15	15.31	-2.15	3.28	0.97	4.07	-2.37**
ExcessSlope	8.72	53.27	-20.05	11.45	0.65	3.56	-3.79***

Note: *, ** and *** respectively stand for significance at 10%, 5% and 1%.

As shown in Table 2, *ExcessLevel* and *ExcessSlope* averagely are significantly positive and the both the *Level* and *Slope* of *IV_Market* are bigger than those of *IV_SVJ*. Our empirical test later will verify whether such difference is caused by market net demand pressure.

2. Building the model-based weighted market net demand pressure

Net position data of different options have been built in the preceding part of this paper and here, according to conclusion of the GPP (2009) model, model-based weighted market net demand pressure will be calculated respectively under three conditions:

Table 3 Calculating method of the sum of model weighted market net demand pressure

Cause of imperfect hedge	Weighted daily net demand pressure

discontinuous trading	$\sum_j (ND_j * f_{ss}^{\ j}(tao, r, M, V))$
Stochastic volatility in the underlying	$\sum_j (ND_j * vega_j(tao, r, M, V) * \frac{(1-\exp(-\phi tao))}{\phi tao})$
Jumps in the underlying	$\sum_j (ND_j * E(K_i K_j))$ $K_j = f^{\,j}(S_t + jumpsize) - f^{\,j}(S_t) - f_s^{\ j} * jumpsize$

In the above table, ND_j is the daily net position of option j, $f^{\,j}(\cdot)$ is the price of option j, $f_s^{\ j}$ is the BS model Delta of option j, $f_{ss}^{\ j}$ is the BS model Gama of option j, $vega_j$ is the BS model Vega of option j, tao is the remaining time of the option, r is the risk-free interest rate (1-year deposit rate in Taiwan), M is the moneyness, V is the implied volatility of option j, ϕ is the mean reversion of volatility in a risk neutral world.

Besides that, to offer an empirical comparison, this paper will again add up simply the net position of different options of each day to get the simple sum of each day's net demand pressure.

For sake of convenience, from here on, the variable of simply summed daily net position will be referred to as *ND_SimpleSum*, the weighted daily net demand pressure under discontinuous trading as *ND_DiscTrade*, the weighted daily net demand pressure under stochastic volatility as *ND_SV* and the weighted daily net demand pressure under jumps as *ND_Jump*.

According to the model of GPP (2009), net demand pressure affects the slope of the implied volatility curve only when under jump risk. Therefore, we use $\sum_j (ND_j * E(K_{M=100\%} K_j))$ as the net demand pressure variable (hereinafter referred to as *ND_Jump_level*) that influences the level adjustment item under jump risk, while $\sum_j (ND_j * E(K_{moneyness=110\%} K_j))$ - $\sum_j (ND_j * E(K_{moneyness=100\%} K_j))$ the net demand pressure variable (hereinafter referred to as *ND_Jump_Slope*) that influences the slope adjustment item under jump risk.

After obtaining data of the model-based weighted net demand pressure with the above method, we proceed to compare level adjustment item with the summed net demand pressure under different risks as well as slope adjustment item with *ND_Jump_Slope* under jump risk and get the following figures:

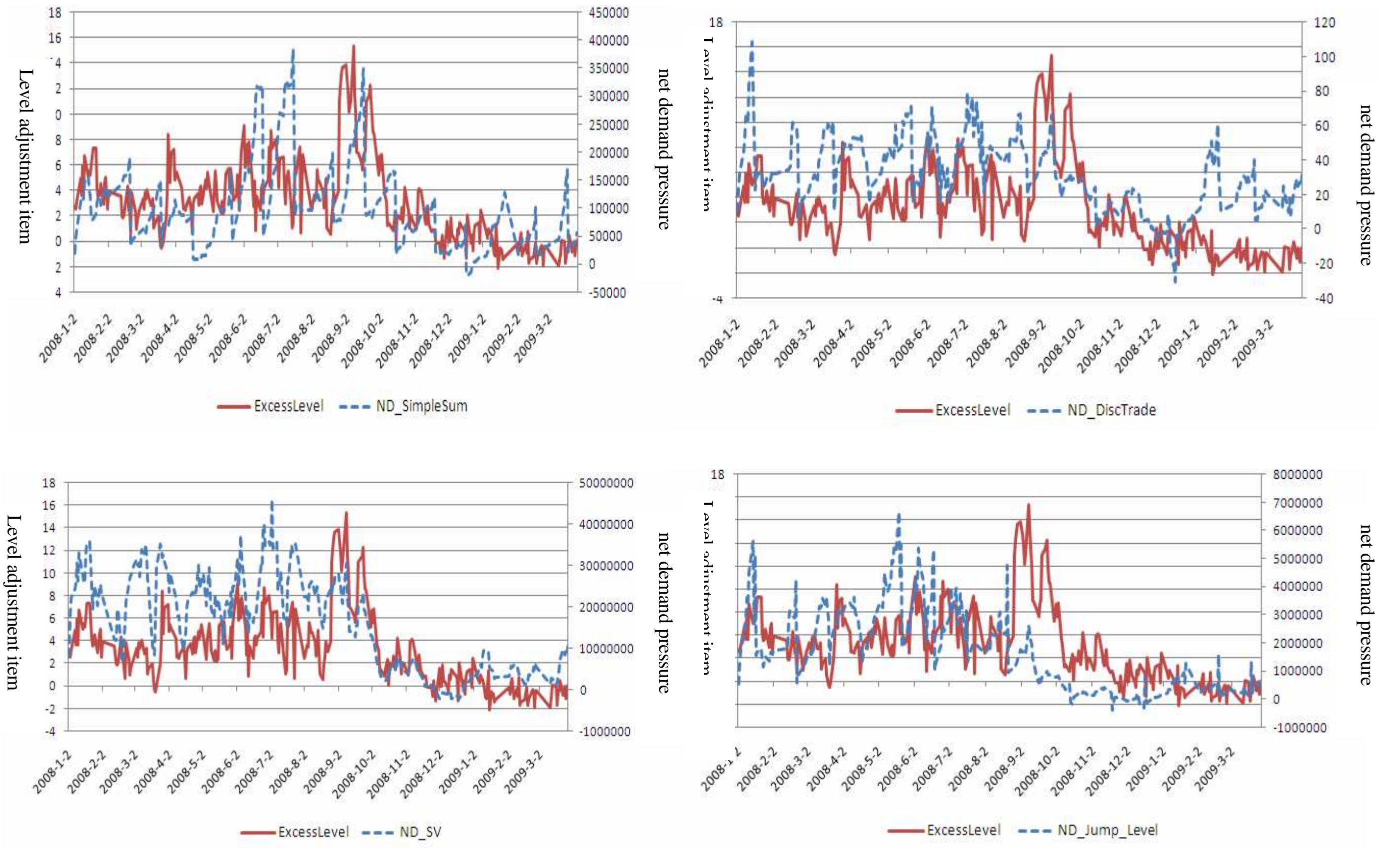

Fig. 8 Level adjustment item and net demand pressure

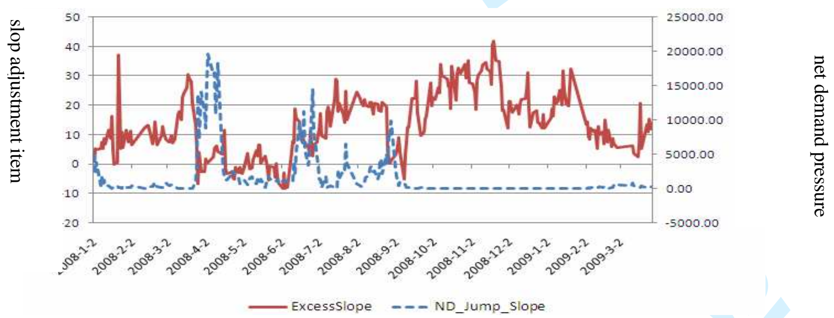

Fig. 9 Slope adjustment item and net demand pressure under jump risk

It's obvious through the diagrams that there is a distinct consistence among the level adjustment item, various weighted net demand pressures and simply summed net demand pressures. But it's hard to tell which net demand pressure variable explains level adjustment item best.

The correlation between slope adjustment item and *ND_Jump_Slope* cannot be intuitively told from the diagrams and the which calls for further regression.

IV. Empirical result⑨

i. Analysis based on hedging risk

In this part, we will conduct empirical test over whether implied volatility is affected by the

⑨ Empirical regression in this part is conducted on the premise of data stationary. Limited by length of paper, stationary test report will not be shown.

hedging risk compensation of market makers and to be more specific, this part can be divided into the level adjustment and slope adjustment of implied volatility.

1. Analysis of level adjustment of implied volatility

According to the conclusion of the theoretical model abovementioned, when market makers are faced with hedging risks, the net demand pressure will impact quotation made by market makers and such impact is not limited to the impact of net demand pressure of a singular option on its own price, but that the net demand pressure of all options of the same underlying assets will exerts influence on the price of one of the options. Two options of the same underlying assets surely will present correlation of hedging risks, because correlation certainly will arise between the prices of two options of the same underlying assets. As a result, the change in one option price due to increased net demand surely will drive changes in another option price. We have put forward following hypotheses:

Hypothesis 1: After removing influential factors of non-net demand pressure, the market net demand pressure of options will exert remarkable impact on the implied volatility of options.

Hypothesis 2: For the implied volatility of individual options, the net demand pressure of all options on the market explains better than own net demand pressure.

On the other hand, based on the demand-based option pricing model, we put forward the following hypothesis:

Hypothesis 3: As for the shape of implied volatility, the weighted sum of net demand pressure obtained through the demand-based model explains better than the simple sum of market net demand pressure.

To test the abovementioned hypotheses, we've built following linear regression equations:

(1) $$ExcessLevel_t = a + bATM\_Demand_t + \varepsilon_t$$

(2) $$ExcessLevel_t = a + bND\_SimpleSum_t + \varepsilon_t$$

(3) $$ExcessLevel_t = a + bND\_DiscTrade_t + \varepsilon_t$$

(4) $$ExcessLevel_t = a + bND\_SV_t + \varepsilon_t$$

(5) $$ExcessLevel_t = a + bND\_Jump\_Level_t + \varepsilon_t$$

where *ATM_Demand* stands for the daily net demand pressure (i.e. daily net position) of ATM options.

The regression result is shown in table 4 and we've come to the following four conclusions:

(1) The five net demand pressure variables all exerts significantly positive impact on *ExcessLevel*. This suggests that the market implied volatility surface, after the impact from stochastic volatility and jump being removed, is significantly affected by the market net demand pressure. And hypothesis 1 is correct.

(2) The *ATM_Demand* is the weakest in interpretation capabilities, with the smallest R^2 9%,

biggest *AIC*5.12 and the biggest logarithm likelihood -748.69. the rest four which are intended to reflect the overall net demand pressure of the market all have better interpretation capabilities than *ATM_Demand*. And this suggests that hypothesis 2 is correct, that is, the price or implied volatility of any option in the market is affected by the net demand pressure of options on the market as a whole.

(3) From the interpretation capability of the sum of the three model-based weighted market net demand pressures and the simple sum of market net demand pressure, the sum of the three model weighted market net demand pressures is better than the simple sum of market net demand pressure and this justifies the correctness of hypothesis 3. The three imperfect hedging conditions based on the model well capture the transmission effect of market net demand pressure on implied volatility.

(4) Among the three imperfect hedging conditions based on the model, the impact degree of net demand pressure is the highest under the underlying assets being with stochastic volatility, with the R^2 reaching 42%, *AIC*4.68 the smallest and the logarithmic likelihood -683.84 the biggest. This suggests that when offering quotations, market makers pay more attention to hedging risks brought about by stochastic changes in volatility, compared with discontinuous trading and jump of underlying assets.

2. Analysis of slope adjustment of implied volatility

According to the conclusions reached by the previous theoretical model, only jump risk can make market net demand pressure exert impact on the slope of implied volatility and therefore we put forward the following hypothesis:

Hypothesis 4: In order to make up for hedging risks caused by jump of underlying assets, market maker will adjust quotation, also the slope of the implied volatility.

To test the above hypothesis, we've built the following linear regression equation:

(1) $$ExcessSlope_t = a + bND\_Jump\_Slope_t + \varepsilon_t$$

(2) $$ExcessSlope_t = a + b\left(Demand_{\mathrm{M=110\%}} - Demand_{\mathrm{M=100\%}}\right)_t + \varepsilon_t$$

where $\left(Demand_{\mathrm{M=110\%}} - Demand_{\mathrm{M=100\%}}\right)$ stands for the daily net position of unweighted Moneyness=110% directly minus the daily net position of unweighted Moneyness=100% and the purpose of bringing in this variable for regression is for comparison with the regression result of model-based weighted ND_Jump_Slope.

The regression result is shown in table 4 and we've come to the following two conclusions:

1. The two regression equation coefficients of slope adjustment are all significantly positive, indicating that the different net demand pressure of options of different Moneyness does affect the slope of implied volatility.

2. From the interpretation capabilities of ND_Jump_Slope weighted by model jump factor and unweighted $\left(Demand_{\mathrm{M=110\%}} - Demand_{\mathrm{M=100\%}}\right)$, the interpretation capability of

ND_Jump_Slope weighted by model jump factor is bigger than that of the unweighted $\left(Demand_{\mathrm{M=110\%}} - Demand_{\mathrm{M=100\%}}\right)$, which suggests that hypothesis 4 is correct. The model-based weighted market net demand pressure captures the transmission effect of market net demand pressure on the slope of implied volatility better. When pricing options of higher moneyness, market makers do take into account the hedging risk brought about by the jump risk of underlying index and have increased the price of options of higher moneyness.

Table 4 Shape of implied volatility—based on hedging risk Analysis

	Excess level					***Excess Slope***	
Constant	1.72***	1.55***	0.91***	1.66***	0.15	10.11***	12.91***
ATM Demand	2.73E-05***						
ND _Simple Sum		1.59E-05***					
ND _Disc Trade			0.07***				
ND _Jump Level				8.87E-07***			
ND _SV					1.88E-07***		
ND _Jump Slope						2.45E-04***	
Demand(M=1.1)-Demand(M=1)							8.27E-05**
Adj. R^2	0.09	0.13	0.19	0.15	0.42	0.11	0.07
S.E.	3.12	3.05	2.96	3.02	2.50	10.7	11.03
AIC	5.12	5.07	5.01	5.05	4.68	7.59	7.64
Log likelihood	-748.69	-742.21	-732.73	-739.18	-683.84	-1110.43	-1118.33

Note: *, ** and *** respectively stand for significance at 10%, 5% and 1%.

ii. Analysis on capital constrain risk

According to conclusions reached by previous models, market makers' risk aversion coefficient exists in the impact of market net demand pressure on option price, which right responds to rising efforts in recent years to study the impact of capital constrain faced by market makers on quotation. That's because the profits or losses of market makers' account will affect their amount of self-possessed funds and consequently affect their attitude towards risks. Therefore, we've put forward the following hypothesis:

Hypothesis 5: Out of concerns over the risk of capital constrain, market makers will adjust their option quotation, which will ultimately affect the shape of implied volatility.

To test the above hypothesis, we suppose that market makers will undertake Delta hedging according to their option position each day and will use the profit and loss (P & L) hedged by such Delta to approximately measure the actual account profits or losses and capital constrain situations. The methods to calculate the daily P&L and accumulated P&L hedged by Delta is as follow:

1. According to the daily net volumes of different options of market makers, work out the daily net position of different options (suppose net position before Jan. 2008 is 0);

2. Suppose the price at which market makers trade is the closing price of options and that market makers conduct daily Delta hedging according to the number of options held.

3. On the following day, suppose market makers calculate the P&L of the day according to the option and underlying asset holding quantity and the Taiwan index and option closing price of the day and previous day.

4. Repeat steps 1-3 of each day to get the daily P&L.

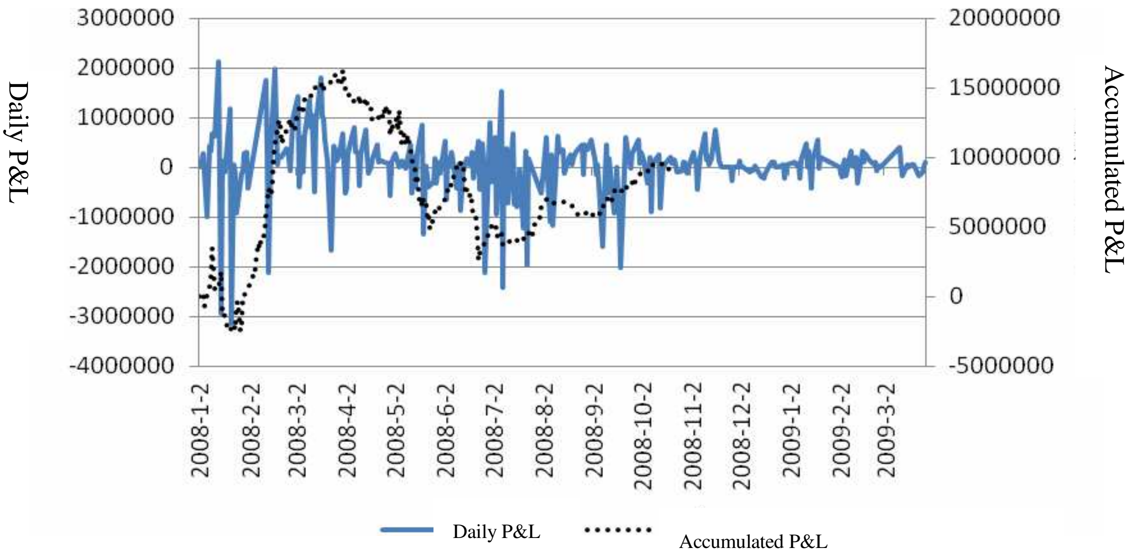

Fig. 10 Daily P&L and accumulated P&L of market makers

The above diagram shows our calculated daily P&L and accumulated P&L, from which we can tell: 1. The daily P&L fluctuates between 2,000,000 and -2,000,000, indicating that although market makers use Delta hedging, still certain risky positions are exposed and market makers reasonably demand certain risk compensations for such hedging risks; 2. Fluctuation of daily P&L may cause joint fluctuation of capital of market makers, which ultimately affects market makers' attitude towards risk-taking; 3. The accumulated P&L suggests that, in the long run, Delta hedging itself can bring market makers certain positive yield.

After obtaining P&L data, we've built the following regression equations:

$$(1) ExcessLevel_t = a + bND\_DiscTrade_t + c(Dummy * ND\_DiscTrade)_t + \varepsilon_t$$

$$(2) ExcessLevel_t = a + bND\_SV_t + c(Dummy * ND\_SV)_t + \varepsilon_t$$

$$(3) ExcessLevel_t = a + bND\_Jump\_Level_t + c(Dummy * ND\_Jump\_Level)_t + \varepsilon_t$$

$$(4) ExcessLevel_t = a + bND\_Jump\_Slope_t + c(Dummy * ND\_Jump\_Slope)_t + \varepsilon_t$$

Dummy will be 1 if the P&L sum of the first 10 working days is positive and 0 if negative. The meaning of such a dummy variable is that if the option hedging profits or losses of market makers affect their option quotation, then parameter *c* should be significantly negative: When the option hedging earnings end up with losses, the impact of net demand pressure on option quotation by market makers will increase, with higher option quotation and the same net demand pressure will lead to more adjustment to the implied volatility; when the option hedging earnings end up with profits, the impact of net demand pressure on option quotation by market makers will decrease, with lower option quotation and the same net demand pressure will lead to less adjustment to the implied volatility.

Regression of the abovementioned equations leads us to the following empirical results:

Table 5 Shape of implied volatility—based on capital constrain risk Analysis (accumulated P&L of first 10 days)

	Excess level			*Excess Slope*
Constant	0.85**	1.61***	0.09	10.40***
ND_DiscTrade	0.08***			
ND_Jump_level		1.06E-06***		
ND_SV			2.00E-07***	
ND_Jump_Slope				0.0002***
Dummy×ND	-0.02	-2.93E-07	-1.93E-08	0.00
Adj. R^2	0.21	0.16	0.43	0.15
S.E.	2.96	3.06	2.52	10.68
AIC	5.03	5.09	4.70	7.59
Log likelihood	-704.57	-713.21	-659.09	-1065.53

Note: *, ** and *** respectively stands for significance at 10%, 5% and 1%.

As shown above, although the coefficient of the dummy variable is negative but not significant. And compared with the regression results in Chapter IV where no dummy variable is considered, no obvious increase in goodness of fit is seen. This suggests that market makers will not change quotations since the accumulated P&L status in the first 10 days won't result in distinct changes in their risk aversion level; therefore hypothesis 5 is false[10]. This is obviously different from our common economic intuition and we believe this is attributable to following reasons:

First, the accumulated P&L obtained through daily Delta hedging cannot well reflect the actual account profits or losses and capital constrain situations of market makers. Income source of market makers includes not only that of Delta hedging, but income from bid-ask spread and other investments. Besides, the method employed by market makers to hedge net option position is not necessarily ordinary Delta hedging and the hedging frequency selected is not necessarily the daily. Therefore, these factors have made our calculated daily P&L or accumulated P&L not actually reflecting the account profits or losses of market makers.

Secondly, even if our calculated accumulated P&L can well reflect the account profits or losses of market makers, market makers may not necessaries increase the option quotation after losses occur. Each market maker has its own limited capital cost. Some of them may start to change option quotations when account profits or losses approach their capital cost. All these factors may effect the regression results.

Therefore, if we want to study the impact of net demand pressure on option quotation by

[10]We've further explored whether market makers will adjust their quotation according to accumulated profits and losses of longer period or, higher or lower than the mean of daily profits or losses. We've separately calculated the mean of accumulated P&L and daily P&L of the first 20 working days and separately take dummy variables and these come to consistence results. Limited by length of paper, empirical results are not shown here.

considering the risk of capital constrain, we may need more data and more studies on the market makers' investment strategies and option hedging methods.

iii. Analysis based on asymmetric information risk

This part will conduct further test of the remaining part after net demand pressure interprets the level portion of the implied volatility, i.e. the residual, to check whether asymmetric information risk affects the level of implied volatility.

First of all, we need to get future information content of the net trading volumes of market investors. Since investors' trading is affected by historical information on the one hand and by future market expectation on the other hand, we've built regression equation 1 to get the portion of net volumes effected by historical return rate, historical volatility and the lag of net volumes. After that, we build regression equation 2 to check whether the residual of equation 1 contains information of future index return rate or volatility. Here we respectively take 0-5 days, 5-15 days and 15-30 days as time intervals to reflect short-term, middle-term and long-term information[11].

(1) $$NV_t^{c,p} = \alpha + \rho NV_{t-1}^{c,p} + \mu_1 R_{(-30)-(-15)} + \mu_2 R_{(-15)-(-5)} + \mu_3 R_{(-5)-0} + \eta_1 \Delta V_{(-30)-(-15)} + \eta_2 \Delta V_{(-15)-(-5)} + \eta_3 \Delta V_{(-5)-0} + \varepsilon_t^{c,p}$$

(2) $$R_{5,t} = \alpha + \kappa\varepsilon_t + \upsilon_t^{R_5}$$

$$R_{15,t} = \alpha + \kappa\varepsilon_t + \upsilon_t^{R_{15}}$$

$$R_{30,t} = \alpha + \kappa\varepsilon_t + \upsilon_t^{R_{30}}$$

$$\Delta V_{30,t} = \alpha + \kappa\varepsilon_t + \upsilon_t^{\Delta V_{30}}$$

$$\Delta V_{15,t} = \alpha + \kappa\varepsilon_t + \upsilon_t^{\Delta V_{15}}$$

$$\Delta V_{5,t} = \alpha + \kappa\varepsilon_t + \upsilon_t^{\Delta V_5}$$

Empirical results are shown in table 6 and table 7:

Table 6 Analysis of historical influential factors of net volumes

	CALL	PUT
α	-2922.67*	-13116.15***
NV_{t-1}^{m}	0.01	0.02
$R_{(-30)-(-15)}$	-10959.16	-3057.56
$R_{(-15)-(-5)}$	5682.46	2249.87
$R_{(-5)-0}$	-14363.14	83413.52***
$\Delta V_{(-30)-(-15)}$	5438.39	13051.85*
$\Delta V_{(-15)-(-5)}$	1298.14	11269.97
$\Delta V_{(-5)-0}$	-3944.37	-369.43
Adj. R^2	0.01	0.14
S.E.	7505.49	10461.11
AIC	20.71	21.37

[11] Since the ADF stationary test shows that the rate sequence is stationary, the volatility sequence is non-stationary and the volatility difference sequence is stationary, the rate and volatility difference sequence will be used during regression.

Log likelihood	-3026.24	-3123.53

Note: *, ** and *** respectively stands for significance at 10%, 5% and 1%.

Table 7 Analysis of future information content of net volumes

CALL	R_5	R_{15}	R_{30}	ΔV_5	ΔV_{15}	ΔV_{30}
α	2.32 E-04	7.28 E-04	8.81 E-04	1.80E-05	-1.15 E-04	1.75E-07
κ	2.34E-07	5.07E-07*	2.03E-07	-3.95E-07	6.26E-08	-8.61E-08
Adj. R^2	0.0002	0.012423	0.0008	0.0021	0.0030	0.0008
S.E.	0.03	0.03	0.03	0.08	0.02	0.01
AIC	-4.10	-4.18	-4.19	-2.18	-4.64	-5.92
Log likelihood	603.32	615.54	617.00	322.45	681.48	869.45

PUT	R_5	R_{15}	R_{30}	ΔV_5	ΔV_{15}	ΔV_{30}
α	2.32 E-04	7.28 E-04	8.81 E-04	1.80E-05	-1.15 E-04	1.75E-07
κ	-1.10E-06 ***	-1.04E-06 ***	-8.59E-07 ***	5.59E-07	-5.49E-08	9.36E-08
Adj. R^2	0.13	0.12	0.09	0.00	0.00	0.00
S.E.	0.03	0.03	0.03	0.08	0.02	0.01
AIC	-4.25	-4.31	-4.29	-2.19	-4.63	-5.92
Log likelihood	624.12	633.29	630.47	323.01	681.50	869.95

Note: *, ** and *** respectively stands for significance at 10%, 5% and 1%.

It can be seen from table 6 that generally when lag net volumes, historical index return rate and volatility are used to interpret the net volumes, they prove weak in interpretation, indicating that the investors' trading is mainly affected by other factors. Net volumes of put options are obviously and positively affected by index rate over the past 5 days and are under positive impact from changes in index volatility over the past 30-15 days. Therefore, lag net volumes, historical index rate and volatility can better interpret put option trading than call option trading.

It can be told from table 7 that the net call option volumes hardly contain forecasting information of future index rate and volatility, while the net put option volumes, on the contrary, obviously contain information of future rate but not information of future volatility. Impact of future rate on the current net put option volumes is significantly negative, indicating that investors can predict the trends within a short period of time by increasing buying volume of put options when expecting weak market. In general, trading of call options does not contain information of future market trends and volatility.

Therefore, we've proven that there are elements of directional information in the net volumes of put options. Then, taking the residual of the above regression equation (1) as an independent variable and the residual that cannot be interpreted by the level of implied volatility as a dependent variable, we will study the interpreting capability of information trading on the level of implied volatility. We've built the following regression equations:

$$(1)\quad Resid\_DiscTrade_t = a + b\ InformVolume_t + \varepsilon_t$$

$$(2)\quad Resid\_JumpRisk_t = a + b\ InformVolume_t + \varepsilon_t$$

(3) $Resid\_StochVol_t = a + b\ InformVolume_t + \varepsilon_t$

Regression results are shown below:

Table 8 Shape of implied volatility----based on asymmetric information risk analysis

	Resid- Disc Trade	*Resid- Jump Risk*	*Resid- Stoch Vol*
C	0.01	0.01	0.00
Inform volume	-3.15E-05*	-4.14E-05**	-2.34E-05
Adj. R^2	0.01	0.02	0.01
S.E.	2.94	3.03	2.53
AIC	5.01	5.06	4.71
Log likelihood	-701.41	-709.13	-658.73

Note: *, ** and *** respectively stands for significance at 10%, 5% and 1%.

We can see from the above results that although we've proven that the put option volumes contain future directional information, asymmetric information risk is weak in interpreting the residual of the implied volatility curve.

Besides that, the directional information elements in the net volumes of put options have negative effect over the residual of implied volatility level after discontinuous trading and jump risk are removed, but it's not significant. But such directional information does not have significant interpreting capability over the residual of the implied volatility level after the stochastic volatility risk is removed. The negative relationship suggests that when the net buying volume with directional information increases, the curve level of implied volatility declines. This conclusion seems to go against economic intuition, for if market makers believe that the net put option buying volume contains information of whether indexes will decline in future, then more buying volume of put options means more likelihood of index fall, so market makers will raise option quotation, which in turn increases the level of implied volatility.

In a word, the goodness of fit of regression equations is very low and the regression results go against economic intuition. We believe that market makers may not care asymmetric information risk implied in put option volumes, they have their own judgment of the direction of future market and the trend of volatility. Market makers adjust the level of the implied volatility curve according to their own judgment of the future market.

V. Conclusions

In this paper, we've conducted empirical tests over the shape of implied volatility of TAIEX Options under the market maker system from Jan. 2008 to March 2009 and have come to the following conclusions:

1. In general, the implied volatility of TAIEX Options resembles a smile. The implied volatility back-calculated from the SVJ model price is smaller than the market implied volatility, especially in terms of deep-out-of-the-money and deep-in-the-money options, which indicats that implied volatility is also affected by factors other than the no-arbitrage model.

2. Market makers care about the hedging risk of whole holding position, so the implied volatility of any option on the market will be affected by the net demand pressure of all options on the market, not merely by its own net demand pressure.

3. The hedging risk faced by market makers and caused by discontinuous trading and the stochastic volatility and jump in the underlying, as depicted in this paper, can well interpret the level of the implied volatility. And the interpreting capability of hedging risk caused by the stochastic volatility is the highest.

4. After considering the hedging risk caused by jump of underlying assets, market makers will make different adjustments to options of different moneyness, therefore the hedging risk caused by jump has certain interpreting capability over the slope of implied volatility.

5. The influence of capital constrain risks on the level of implied volatility is not significant. Due to unknown about investment strategies and option hedging methods applied by market makers, further researches are needed in future.

6. Under the risk of asymmetric information, only the net volume of put options contains directional information. However, market makers may not care about losses from dealing with informed traders and the influence from asymmetric information risk on the level of implied volatility is not significant.

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