# What Caused Chinese Warrant Price Deviations: Speculation or Creation Mechanism?*

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**Abstract**

By empirical studies of Chinese warrants pricing, we find there are systematic deviations in warrants price that call warrants are under valued and put warrants are over valued. Using high frequency data, we do further researches about the reasons of systematic deviations according to the prospect theory and resell option theory owing to heterogeneous beliefs. There are different story for Call Warrants and Put Warrants price deviations. For Call Warrants, the special creation mechanism cause reference prices play a important role in explaining the under valuation of Call warrants, and the turnover of Warrants do not. So the prospect theory dominate the resell option theory in Call Warrants case. For Put Warrants, the turnover of Warrants play a important role to explain the over valuation of Put Warrants, the resell option theory dominate the prospect theory, which consistent with Xiong and Yu (2011).

Keywords: warrant price deviations, mental account, resell option, heterogeneous belief creation mechanism
JEL: G13, G14

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# 1 Introduction

After first Chinese warrant JTB1 was issued at Shanghai Securities Exchange, Chinese warrants have attracted lots of investors (include speculators) to enter into the market. Up to August 22 of 2005, There were 55 warrants were issued, 38 in Shanghai Securities Exchange and 17 in Shenzheng Stock Exchange. Their trade volume and turnover are so huge that they surpassed hongkong warrant market, which have 4500 warrants. Besides huge turnover and trade volume, another hot issue is big price deviation from fundamental value in Chinese warrants.Qin (2006), Wang and Ding (2007), Wang and Hu (2009), Wu (2009) etc.find there are significant deviation between BS model prices (Black-Scholes Option Pricing Model) and market prices; Wang (2008) find there exit negative risk premiums in Chinese call warrants; Song and Zhang (2008),Ouyang (2009) argue that the main reason caused bid price deviation in Chinese warrants market is due to lack short sell mechanism which prevent the arbitrage trading, but Hao Qin (2006) attribute it to investor's speculation behaviors.Xiong and Yu (2011) do a great empirical studies on Chinese put warrants, they find there exit a price bubble in Chinese warrants and resell option theory can explain it well, they argue that noise trader's speculation behavior is the main reason caused the bubble. But they didn't analyse the put warrants.For market governor, the main question is what caused Chinese warrants price deviate significantly? Is it due to investor's over speculation or warrant market mechanism? We still need further researches.

The price deviation of warrants can be separated to two parts. one is due to option pricing model, and another one is due to microstructure and investor's speculation. This paper focuses the second one. But we still need control the effects of first part factors to make our analysis more accurately.

Black-Scholes Model (BS) is the most famous option pricing model, but it has a disadvantage which can not explain the volatility smile that Implied volatilities calculated from option market prices show a convex curve with respect to exercise price. After BS model, people want to explain volatility smile by adopt various underline asset return process. there are two main approaches to solve this problem. one is so called deterministic volatility model which represented by Derman, Ergener, and Kani (1995), Derman and Kani (1994),Dupire (1994), Rubinstein (1994) etc. These models assume the underline asset volatilities is a deterministic function of underline asset price and time, solve the option value in complete market. oppositely, stochastic volatility model assume the volatilities of underline assets is a stochastic process, such as Hull and White (1987),Scott (1987),Wiggins (1987),Merton (1976),Bates (1996a,b),Jiang (1999),Scott (1997) etc. in this case we need make some assumption about market risk premium to solve the option price. GARCH option pricing model belongs to deterministic volatility model, which take volatilities variation into account and can valuate options price with martingale approach. Although these models can partially explain volatility smile, but there still exit big pricing errors. Dumas, Fleming, and Whaley (1998),Das and Sundaram (1999) etc. do some empirical studies about them and show the disadvantage of these models.

Recently some literatures try to explain the volatility smile from the perspective of market microstructure and liquidity. Ignacio Pena and Serna (1999) shows that liquidity of options can affect volatility smile significantly; Norden (2003) find that the asymmetry of risk suffered by option's buyer and seller have some effect on volatility smile; Xiong and Yu (2011) shows that investor's speculation from heterogeneity caused Chinese put warrant bubbles.

Chinese warrants market has very special creation mechanism. Institution want to issue call warrants need to deposit plenty of underline assets to satisfy exercise by counter-party.

On the other hand, institution issuing put warrants just need to deposit certain amount cash required by counter-party exercise. So, there is not risk for issuer of call warrants because they can just sell the stocks deposited even if the counter-party want to exercise the warrants. but the issuer of put warrants always confront the risk when the counter-party exercise the warrants. This paper focus the characteristics of Chinese warrants creation mechanism and try to explain the price deviation using prospect theory and resell option theory.

First, we adopt two typical option pricing model: GARCH option pricing model and BS model to get the theoretic option price and price deviation. We use **EMS** (Empirical Martingale Simulation) proposed by Duan and Simonato (1998) to get the GARCH model theoretic option price. The empirical results show that there exist systematic overvalue in Chinese put warrants and systematic undervalue in Chinese call warrants. Only very small price deviation due to pricing model selection. Then we propose a theoretic model based on prospect theory and resell option theory and make a empirical studies with high frequency data. The model can explain Chinese warrant price deviation relatively well, the $R^2$is above 90%. Our results show that the strict requirement of warrant creation make few institution have the bargaining power in the warrant pricing. As a result, the cost of issuer has a significant effect on reference price of individual investors. The special creation mechanism of Chinese warrant is the main reason caused Chinese warrants deviation, which make the reference price lower for call warrant buyer and higher for put warrant buyer. The individual investor's speculation behavior owing to heterogeneous belief can only explain a small parts of price deviations. It is first time to explain the Chinese warrant systematic price deviation using prospect theory and resell option theory and argue that warrants creation mechanism is the main reason to lead to the big price deviations. It is very important to keep Chinese warrant market developing stably.

The paper is organized as follows.Section 2 calculate the option theoretic price using GARCH model and BS model and analyse the characteristics of Chinese warrant price deviations; Section 3 analyse the factors affected warrant price deviations, first we analyse it theoretically, then make empirical studies using panel data to test it; Section 4 summarizes the main results of the paper.

# 2 Warrant Price Deviations

## 2.1 GARCH Option Pricing Model

Our sample only include covered warrants to avoid the effect of diluting shares causing additional pricing errors. Further more,we exclude the warrants which time to expiration are less than 20 days, so that we can regard the bermuda options as European options. We take the BS model and GARCH model proposed by Duan (1995) as our warrant pricing models and describe sketch as following.

Assume the stock price $S_t$ at time $t$ following the non-asymmetry GARCH process un probability measure $P$,

$$\ln \frac{S_t}{S_{t-1}} = r + \lambda\sigma_t - \frac{1}{2}\sigma_t^2 + \sigma_t\epsilon_t \tag{1}$$

$$\sigma_t^2 = \alpha_0 + \alpha_1\sigma_{t-1}^2(\epsilon_{t-1} - \theta)^2 + \alpha_2\sigma_{t-1}^2$$

$$\epsilon_t|\phi_{t-1} \sim N(0,1)$$

Where $\phi_{t-1}$ is the information sets available to the agent up to and include time $t$; $r$ is risk free rate; $\lambda$ is the market price of risk. To ensure volatility $\sigma_t$ stationary, $\alpha_1 + \alpha_2 < 1$ is assumed. If $\alpha_1 = 0$ and $\alpha_2 = 0$, then volatility $\sigma_t$ is a constant, the model becomes BS model, in another words, BS model is a specificated case of GARCH option pricing model. To get option price, Duan (1995) proposed Locally risk-neutral valuation relationship(LRNVR), he shows that there is the risk neutral probability measure $Q$ under which $S_t/S_t - 1$ can become a log-normal distribution,[1]

$$\ln \frac{S_t}{S_{t-1}} = \nu_t + \eta_t \xi_t \tag{2}$$

, Where $\nu_t$ is conditional expectation, and $\xi_t$ is a standard normal distribution under probability $Q$, $\eta_t$ is a constant. According to LRNVR [2], We have,

$$Var^Q\left(\ln\left(\frac{S_t}{S_{t-1}}\right)\bigg|\phi_{t-1}\right) = Var^P\left(\ln\left(\frac{S_t}{S_{t-1}}\right)\bigg|\phi_{t-1}\right)$$

so, $\eta_t = \sigma_t$. On the other hand, we have,

$$\begin{aligned} E^Q\left(\frac{S_t}{S_{t-1}}\bigg|\phi_{t-1}\right) &= E^Q(\exp(\nu_t + \eta_t\xi_t)|\phi_{t-1}) \\ &= \exp(\nu_t + \frac{1}{2}\sigma_t^2) \end{aligned}$$

[1] Duan (1995) show that if the utility function of representative agent is time separable and additive, and satisfy one of three conditions, then locally risk-neutral valuation relationship (LRNVR) holds.

1. Utility function is of constant relative risk aversion and the distribution of changes of logarithmic aggregated consumption is normal distribution with constant mean and variance under measure P.
2. Utility function is of constant absolute risk aversion and the distribution of changes of logarithmic aggregated consumption is normal distribution with constant mean and variance under measure P.
3. Utility function is linear.

[2] Locally risk-neutral probability measure $Q$ is the probability measure which is mutually absolutely continuous with respect to probability measure $P$, and satisfy the following 3 conditions.

1. $S_t/S_{t-1}|\phi_{t-1}$ is log-normal distribution under probability measure $Q$.
2. $E^Q\left(\frac{S_t}{S_{t-1}}\Big|\phi_{t-1}\right) = \exp(r)$
3. $Var^Q\left(\ln\left(\frac{S_t}{S_{t-1}}\right)|\phi_{t-1}\right) = Var^P\left(\ln\left(\frac{S_t}{S_{t-1}}\right)\Big|\phi_{t-1}\right)$ a.s. that is, probability measure $P$ and probability measure $Q$ are equivalent.

where $E^Q(\bullet)$ is a operator of expectation under probability measure $Q$. $Var^P(\bullet)$ and $Var^Q(\bullet)$ represent volatilities under probability measure $P$ and $Q$ respectively.

According to property 1 of LRNVR,$E^Q\left(\frac{S_t}{S_{t-1}}\middle|\phi_t - 1\right) = \exp(r)$, so we have $\nu_t = r - \frac{1}{2}\sigma_t^2$. Comparing formula (1) and formula (2), we can get,

$$\epsilon_t = \xi_t - \lambda$$

so we can ge the following formula under $Q$,

$$\ln\frac{S_t}{S_{t-1}} = r - \frac{1}{2}\sigma_t^2 + \sigma_t\xi_t \tag{3}$$

$$\sigma_t^2 = \alpha_0 + \alpha_1\sigma_{t-1}^2(\xi_{t-1} - \theta - \lambda)^2 + \alpha_2\sigma_{t-1}^2$$

$$\xi_t|\phi_{t-1} \sim N(0,1)$$

Adding up $S_t$ from time $t$ to $T$, we have,

$$S_T = S_t \exp\left[r(T-t) - \frac{1}{2}\sum_{s=t+1}^{T}\sigma_s^2 + \sum_{s=t+1}^{T}\sigma_s\xi_s\right] \tag{4}$$

The discount process $\exp(-rT)S_T$ is a martingale under probability $Q$, so we can get the call option price ($C_t^{GH}$) and put option price ($P_t^{GH}$) as following,

$$C_t^{GH} = \exp(-r(T-t))E^Q\left[\max((S_T - K), 0)|\phi_t\right]$$

$$P_t^{GH} = \exp(-r(T-t))E^Q\left[\max((K - S_T), 0)|\phi_t\right] \tag{5}$$

where $K$ is exercise price.

## 2.2 Sample

We employ the one minute high frequency data of Chinese covered warrants from 2005 to 2009. There are 10 call warrants and 18 put warrants in our sample. All of them are bermuda options except JTB1, PGP1,JTP1, JCP1, JTP1 which are European Options. We exclude the data which time to maturity are less than 20 days so as to we can treat them as European options.

- We adjust the exercise price and exercise ratio based on information according to "Warrants Management Measure" of Shanghai Stocks Exchange, that is, New Exercise Price = Original Exercise Price $\times A$ (Underline Stock reference Price one day prior to ex dividend date or ex rights date) $\div$ (Underline Stock Closed Price one day prior to ex dividend date or ex rights date); Stock Reference Price = [(closed price of previous day - cash dividend ) + rationed shares price $\times$ the ratio of change in negotiable share ]$\div$ (1 + ration change in negotiable share) New exercise Price = origenal exercise price $\times$ (closed price of previous day $\div$ reference price of stocks). There is no changes in the ratio of exercise when the underline stock has ex dividend.
- To calculate option price, we take the average value of warrants (stocks) price trading from 14:45 to 15:00 as daily close price to avoid non-synchronic problem.
- To get the risk free rate, we convert the 7 days repo rate of national bond into the continuous rate.

## 2.3 Warrants Pricing Errors

We describe the details to calculate the theoretic price of warrants and their pricing errors using BS model and GARCH model proposed by Duan (1995) as following, To get warrant price at day $t$ with BS model, we adopt the volatilities calculated using high frequent data of underline stocks on day $t-1$. Repeating this procedure, we can get all of warrants price using BS model.

To get GARCH model theoretic price of warrants, we use **Empirical Martingale Simulation (EMS)** proposed by Duan and Simonato (1998) to improve the simulation accuracy. This method can keep the martingale property of discounted value process even if the number of sample path is finite, so the confidence interval of warrant prices can be reduced.

We calculate GARCH model theoretic price of warrants $C_t^{GH}$,$P_t^{GH}$ at time $t$ as following steps.

1. Estimate the parameters ($\alpha_0$,$\alpha_1$,$\alpha_2$,$\theta$,$\lambda$) using 750 days data backwards from last Friday before day $t$.

2. Calculate the initial volatility $\sigma_0$ to do monte carlo simulation with formula (4) using the high frequent data of day $t-1$.

3. Calculate the warrant prices at day $t$ according to formula (5) using **EMS** based on parameters $\alpha_0$,$\alpha_1$,$\alpha_2$,$\theta$,$\lambda$ and $\sigma_0$.

4. Repeating step 1 to step 3 we can get all of warrants prices of each days.

We adopt warrant price deviation to show how different between warrant market prices and its theoretic prices, and define it as following,

$$\text{warrant price deviation} = \text{warrant market price - warrant theoretic price}$$

**Table 1** and **Table 2** show the describe statistics of the variables involve call warrants and put warrants. First, we can see Chinese warrant price deviation are very huge. Using

GARCH option pricing model, they are -2.0328 comparing with the theoretic price 5.1634 on average for Call Warrants, and 1.1729 comparing with the theoretic price 0.0010 on average for Put Warrants. Using BS model, they are -2.0504 comparing with the theoretic price 5.1810 on average for Call Warrants, and 1.1277 comparing with the theoretic price 0.0462 on average for Put Warrants. Even though GARCH model take the fat tail and volatility asymmetry between price going up and going down into account, but the performances are improved very limitedly comparing to BS model. Second, comparing to call warrants, the theoretic prices of put warrants are very approach to zero. Most of call warrants are deep in-the-money and most of put warrants are deep out-of-the-money, because the stock prices keep going up in our sample period. We also can find another interesting phenomena that the price deviations of call warrants are negative on average but they are positive on average with put warrants. We intuitively get this information from **figure 1** and **figure 2**. In summary, there are systematic under valuation in call warrant and systematic over valuation in put warrant.

What caused Chinese warrant price systematic deviations? We can get some explain from volatility smile. **Figure 3** and **4** show the variations of price deviations with respect to moneyness, which are calculated based on GARCH model and BS model respectively. The figures appear "price deviation smile". So some of price deviations can be explained partially by moneyness of warrants according to the curve of smile, but there are still big deviations can not be explained. We try to explain it from perspective of warrant creation mechanism and investors speculation behaviors following sections.

# 3 Analysis of Warrants Price Deviations

Some of literatures explain Chinese warrants deviations with perspective of speculation behavior of investors, and some literatures explain it by short sell constrain of Chinese warrants market. But none of them can explain the under valuation of call warrants. We try to synthesize market mechanism and speculation behavior of investors to explain it. First, we adopt “mental account theory ”to analyse the effect of warrant creation mechanism on price deviations, then adopt resell option theory to take the speculation behavior of investors into account.

## 3.1 Chinese Warrants Creation Mechanism

According to ”interim measure of administration for warrants of Shanghai Stock Exchange” (we call it ”interim measure” hereafter), the issuers of warrants should pay margin as following rules, which are issued by third party of underline stocks issuers and is trading at the Shanghai Stock Exchange. (1) Deposit enough underline securities or cash to specified account as margin. amounts of stocks = warrants quantity of issue × exercise ratio × guarantee coefficient; amounts of cash = warrants quantity of issue × exercise ratio × guarantee coefficient; (2) provide the joint liability guarantor who is approved by Shanghai Stock Exchange.

”Notice on the Relevant Issues Concerning securities company creating WUGANG warrants” (we call it ”Notice” hereafter) was published by Shanghai Stock Exchange on November 21 of 2005. According to ”Notice”, Newly created warrants must keep same underline stock, exercise price, exercise condition and maturity. further more, for those securities company who issued call warrants, they must deposit enough underline stocks to the specific guarantee account to sell underline stocks if counter party exercise warrants; for those securities company who issued put warrants, they must deposit enough cash to the specific guarantee account to buy the underline stocks if counter party exercise warrants;

So there are some characteristics in Chinese warrants creation mechanism, we can summarize them as following,

- Only qualified securities companies can issue warrants. Even if qualified securities companies can not create warrants freely, so there is short sell constrain in Chinese warrant market.

- After warrants are issued, newly created warrants must keep the same exercise price as original warrants. This lead to most of call warrants being deep in-the-money and most of put warrants being out-of-the-money because stocks price go up dramatically.

- For those securities company who issued call warrants, they have get ready all of underline stocks for counter party exercising warrants, so they don't have any risk actually. During the period in which stocks boom, the probability call warrants can be exercised is almost 100%,so securities companies just need to sell the underline stocks they deposited and get the warrants premium without risk. The cost they created warrants is $S_t - Ke^{-rT}$, their profits are always positive if the premium of warrants is higher than that cost. So they can be tolerant of relatively lower call warrants price.

- For the securities company who issued put warrants, the situation is different, they still confront risk to loose money when counter party exercise the warrants. The cost they created warrants is "put warrants value + interest rate of cash margin $K(1 - e^{-rT})$". Put warrants value are almost zero during the period stocks going up dramatically, but securities companies are still pay the interest rate cost, so they must require higher warrants price to avoid loss.

Next section we build a model based on ”mental account theory” and ”resell option theory” to make more deep analysis.

### 3.2 Theoretic Model

Grinblatt and Han (2005) use “metal account theory ”to explain the momentum of stocks. We refer their model to explain Chinese warrants price deviations. Assume there are two types of investors, one is reasonable investor and another one is PT/MA investors. The ratio of PT/MA investors to total investors is $\mu$. Assume the demand function of two types of investors are as following.

Demand function of reasonable investor:

$$D_t^{rational} = 1 + b_t(F_t - P_t^W) \tag{6}$$

Demand function of PT/MA investor:

$$D_t^{PT/MA} = 1 + b_t[(F_t - P_t^W) + \lambda(R_t - P_t^W)] \tag{7}$$

where $P_t^W$ is market price of warrants; $R_t$ is the reference price of PT/MA investors which is known before time $t$; $\lambda$ is a positive constant which shows how important the capital gain is for PT/MA investors; $b_t$ represents the slop of demand of rational investors for warrants price. $F_t$ is the warrants price if there were not effects from PT/MA investors. By aggregating both type investor's demand functions and making market clear, we can get market equilibrium price easily,

$$P_t^W = wF_t + (1 - w)R_t \tag{8}$$
$$w = \frac{1}{1 + \mu\lambda}$$

Notice that $0 < w < 1$, the relationship between warrants market price $P_t^W$ and $F_t$ depends on which one is bigger between $F_t$ and $R_t$. that is, if $R_t < F_t$, then $P_t^W < F_t$; otherwise, $P_t^W > F_t$.

$F_t$ represents the warrants price without the effect from PT/MA investors, it can be affected by resell option,so we can introduce the resell option into above model. Miller (1977), Harrison and Kreps (1978) and Scheinkman (2003) etc. proposed resell option models under static and dynamic situation respectively. The main idea is that investors have different brief about future, if there is short sell constrain, even if the optimistic investors can buy the asset which price is high for them because they think there are another investors who are more optimistic than themselves, so they can sell the assets to those more optimistic investors. As results, asset price will be going higher and higher and causing bubble. There is short sell constrain in Chinese warrants market.[3]further more, over 90% investors are individual investors, it suggest the difference of investor beliefs are very big, so it is satisfied the assumption of resell option theory. But warrants are different from stocks, because they are influenced by both stocks and themselves.

Assume the stock price without resell option at time $t$ is $S_t$, resell option value is $RO_s(\gamma, t)$, $\gamma$ is the investor's belief. Then the observed market price of stock $S_{\text{real}}$ can be represented

[3]Although the qualified securities companies can create the warrants, but the requirement is very strict, so we can think there is short sell constrain in Chinese warrants market.

as,

$$S_{\text{real}} = S_t + RO_s(\gamma, t)$$

If we ignore the influence of resell option, the price of call warrants and put warrants can be regarded as a function of stock price $S_{\text{real}}$ and time $t$, we represent them as $f(S_{\text{real}}, t)$ and $g(S_{\text{real}}, t)$ respectively. assume the resell option value of call warrants and put warrants are $RO_C(\gamma, t)$ and $RO_P(\gamma, t)$ respectively, then call warrants price without influence of PT/MA investors is,

$$\begin{aligned} F_C &= f(S_{\text{real}}, t) + RO_C(\gamma, t) = f(S_t + RO_s(\gamma, t), t) + RO_C(\gamma, t) \\ &\approx f(S_t) + f_S(S_t, t) \times RO_s(\gamma, t) + RO_C(\gamma, t) \end{aligned} \tag{9}$$

$f_S(S_t, t)$ is the partial derivative of $f(S_t, t)$ with respect to $S_t$. From (9), we can see there are positive correlation between call warrants price and resell option reduced by heterogenous beliefs. As the same way, put warrants price without influence of PT/MA investors is,

$$\begin{aligned} F_P &= g(S_{\text{real}}, t) + RO_P(\gamma, t) = g(S_t + RO_s(\gamma, t), t) + RO_P(\gamma, t) \\ &\approx g(S_t) - |g_S(S_t, t)| \times RO_s(\gamma, t) + RO_P(\gamma, t) \end{aligned} \tag{10}$$

where $g_S(S_t, t)$ is the partial derivative of $g(S_t, t)$ with respect to $S_t$. Substitute (9) and (10) into (8) respectively, we can get the formulas about market price of call warrants $P_t^C$ and market price of put warrants $P_t^P$,

$$P_t^C - f(S_t) = (1-w)(R_t - f(S_t)) + wf_s(S_t,t)RO_s(\gamma,t) + wRO_C(\gamma,t) \tag{11}$$

$$P_t^P - g(S_t) = (1-w)(R_t - g(S_t)) - w|g_s(S_t,t)|RO_s(\gamma,t) + wRO_P(\gamma,t)$$

According to above model, we can see that call warrant (put warrant) price deviations is proportional to the difference between reference price and the theoretic price of warrants. The bigger the difference of beliefs among stocks investors are, the higher call warrants price deviations are, and the lower put warrants price deviations are; The bigger the difference of beliefs among warrants investors are, the higher call warrants (put warrants) price deviations are. We will test our model using data next section.

## 3.3 Empirical Analysis

### 3.3.1 Reference Price

The cost can be regarded as reference price of individual investors,of which institutions issue(create) warrants. It is bull market during our sample period, the stock prices persistently go up, so Call Warrants are in the deep-in-the-money, and the put warrants are in the deep-out-of-the-money. In other words, the Call Warrants must be exercised by the counterparty. To create the Call Warrants, the issuer must get the underlying stocks in advanced, and deposit them into the special account. If the Call Warrants are exercised by the counterparty, the issuer just need to sell the stocks in the special account to the counterparty, and get the cash amount $Ke^{-rT}$. So, the created cost of the Call Warrants for the issuer is,

$$\text{Cost} = S_t - C_t - Ke^{-rT} \tag{12}$$

The condition to make the issuer want to create the Call Warrants is the created cost is zero. So, we get the reference price of the issuer as following,

$$R_{F_t} = S_t - Ke^{-r(T-t)} \tag{13}$$

We know that the lower bound of the Call option is,

$$F_{C_t} \geq \mathrm{MAX}(S_t - Ke^{-(T-t)}, 0) \tag{14}$$

So, we have,

$$R_{F_t} \leq F_{C_t} \tag{15}$$

According to formula (8), we can predict the market prices of Call Warrants are more likely lower than its theoretic prices.

But, for the Put Warrants, they are deep-out-of-the-money,so there are almost no chances to be exercised by the counterparty. To create the Put Warrants, the issuer need to save the cash K into the special account. So, the created cost of the Put Warrants for the issuer is,

$$\mathrm{Cost} = K - F_{P_t} - Ke^{-r(T-t)} \tag{16}$$

The condition to make the issuer want to create the Call Warrants is the created cost is zero. So, we get the reference price of the issuer as following,

$$R_{F_t} = K - Ke^{-r(T-t)} = K(1 - e^{-r(T-t)}) >> 0 \tag{17}$$

During the sample period, the theoretic prices of the Put Warrants is almost zero, so in the most case,

$$R_{F_t} > F_{P_t} \tag{18}$$

According to formula (8), we can predict the market prices of Put Warrants are more likely bigger than its theoretic prices.

After warrants are issued, warrants market prices can be volatile, so the reference price of PT/MA investor also need to be updated. We assume the PT/MA investor update their reference price according to the following rule,

$$R_{t+1} = V_t P_t^W + (1 - V_t) R_t, \text{ if } V_t < 1;$$

$$R_{t+1} = P_t^W, \text{ if } V_t \geq 1. \tag{19}$$

Where, $V_t$ is the turnover of warrants at time $t$.

**Figure (5-8)** show the variation of the reference prices, the GARCH option price, the market prices of Warrants and the Moneyness with respect to time. We can clearly see that almost all of the Call Warrants are deep-in-the-money, and almost all of Put Warrants are deep-out-of-the-money. We can also see that the reference price for call warrants is significantly lower than theoretic price of warrants. According to formula (8), we can infer that the market price of call warrants is lower than its theoretic price. on the other hand, the reference price for put warrants is significantly higher than theoretic price of warrants, this imply that the market price of put warrants is higher than its theoretic price. This inference offers an explanation to the warrants price deviations we got in section 2.

#### 3.3.2 Variables Selection

Besides the variables including in model (11),e.g. reference price and turnover of stocks and warrants, we also choose the variables which might affect warrants price deviations, e.g. net-buy pressure, liquidity, cumulated warrant creations, moneyness, time to maturity.

**Heterogenous belief proxy** Heterogenous belief represents investor's different conjecture about future price trend. The bigger the difference of belief about future, the more frequent the trade is. So turnover is usually adopted as the proxy of it in many literatures, e.g. Mei, Scheinkman, and Xiong (2009),Xiong and Yu (2011),Wang and Ding (2007). So we also use the turnovers of stocks (turnovers of warrants) as the proxy of stocks investor's heterogenous belief (warrants investor's heterogenous belief).

According to theoretic inference, the turnover of stocks is positively correlated with call warrants price deviations and negatively correlated with put warrants price deviations; The turnover of warrants is positively correlated with call (put)warrants price deviations.

**Measure for bubbles of stocks** Wang and Zhu (2012)argue that the investors will make rational hedge if there are bubbles in stock prices. If the bubble is high, the stock price are expected to fall, the investors will buy Put Warrants, the Put Warrants price will go up. Otherwise, if the bubble is negative, the demand for Call Warrants increase, and the Call Warrants will go up. According to Wang and Zhu (2012), we run the rolling dynamic AR(1) regression,

$$S_t = \alpha_0 + \lambda_t S_{t-1} + e_t \tag{20}$$

$\lambda_t$ is a proxy of the bubbles' tendency to accumulate or to burst during the sample period.

**Liquidity proxy** There are lots of measures of liquidity which can measure different four dimensions (width, depth, immediacy, immediacy). here we only adopt "width" measure, bid-ask spread. Because we don't have information about bid and ask price, so we use the method proposed by Roll (1984) to estimate it.

$$spread = \frac{1}{2}\sqrt{-cov(\Delta P_t, \Delta P_{t-1})} \tag{21}$$

We use warrants (stocks) high frequent data from day $t-5$ to $t$ to estimate the bid-ask spread of day $t$, written as $spread_t$, $spread\_stock_t$ respectively.

**Net Buy Pressure** We adopt the method proposed by Bollen and Whaley (2004) to calculate net buy pressure.

**Step 1** Calculate bid-ask spread $spread_t$ of day $t$ using the high frequent data from day $t-5$ to $t$ according to the method proposed by Roll (1984).

**Step 2** Assume warrants price at time $\tau$ is $P_\tau$, if $P_{\tau+1} > P_\tau + spread_t$, we regard the volume at time $\tau$ as buying motivated volume, otherwise, if $P_{\tau+1} < P_\tau - spread_t$, regard the volume at time $\tau$ as selling motivated volume. Repeating this procedure, get all of buying motivated volume (selling motivated volume) of day $t$.

**Step 3** Aggregate the buying motivated volume, selling motivated volume of day $t$ respectively. Take the difference between total buying motivated volume and total selling motivated volume of day $t$ to get the net-buying pressure of day $t$.

To exclude the effect of trade volume, we standardize the net-buying pressure on day $t$ by divided by trade volume of day $t$. According to theoretic inference, the bigger the net-buying pressures are, the bigger the warrants price deviations are.

**Cumulated Warrants Creation** There are strict requirement for institutions to create warrants in Chinese warrants market, so actually there is short sell constrain in Chinese warrant market. Even if the market price is high, investors can not take arbitrage trade to inhibit the prices. But some qualified securities companies can create warrants discretely, we can regard it as a sort of "short sell". so we adopt cumulated warrants creation as the proxy of short sell to test the effect of short sell on warrants price deviations. According to theoretic inference, cumulated warrants creation are negatively correlated with warrants price deviations.

**Moneyness** Moneyness (the ratio of which the underlying asset price divided by exercise price) can affect the option prices. Volatility smile means that the implied volatilities which are calculated using option market prices according to BS model present a convex curve with respect to moneyness. It is widely observed in many option markets. For example, Rubinstein (1994) examines it in the S&P 500 Index option market, and Duque and Paxson (1994) analyze the London International Financial Futures Exchange (LIFFE), and Kim (1996) investigates the Nikkei 225 Index option market [4]. Based on the volatility smile, the more close to deep in-the-money or deep out-of-the-money the warrants are, the bigger the price deviations are. Even if we take the variation of volatilities into account, volatility smile can not yet be explained com-

[4]More recently, (Dumas, Fleming, and Whaley (1998), Branger and Schlag (2004), Foresi and Wu (2005), Lin and Paxson (2008), Chang and Shi (2009)) investigate the "volatility sneer" or "volatility smirk" phenomena in many option markets, which means that the implied volatilities decrease monotonically as the exercise prices rise relative to the index level.

pletely. According to descriptive statistics, we can see most of call warrants are deep in-the-money and most of put warrants are deep out-of-the-money, it might affect the warrants price deviations. So we take the moneyness (represented by $moneyness_t$) and the square of moneyness (represented by $moneyness_t^2$) as control variables.

#### 3.3.3 The Results of Empirical Studies

**Tbale 1** and 2 show the descriptive statistics of all the variables. The average moneyness is 1.4679 for call warrants, and 0.8221 for put warrants. It means call warrants are deep-in-the-money and put warrants are deep-out-of-money. For turnover, the daily average turnover is 0.4360 for call warrants and 0.7548 for put warrants, are much higher than the daily turnover of underline stocks. The daily turnover of underline stocks is 0.0165 during the Call Warrants sample period, and 0.0176 during the Put Warrants sample period. We can easily infer that the speculation in warrants market is much higher than in stocks market.

Based on the selected variables, we can build the following panel data model:

$$\begin{aligned}\text{Model (1): } pricing\_error_{it} &= \beta_0^1 + \beta_1^1 diff\_RF_{it} + \beta_2^1 spread_{it} + \beta_3^1 spread\_stock_{it} \\ &+ \beta_4^1 turnover\_warrant_{it} + \beta_5^1 turnover\_stock_{it} + \beta_6^1 dumy\_issue_{it} \\ &+ \beta_7^1 cummulate\_created_{it} + \beta_8^1 Moneyness_{it} + \beta_9^1 Moneness_{it}^2 + \beta_{10}^1 \lambda_{it} + \varepsilon_{it}^1 \end{aligned} \tag{22}$$

$$\varepsilon_{it}^1 = \alpha_1^1 + \eta_{it}^1$$

Model (2): $pricing\_error_{it} = \beta_0^2 + \beta_1^2 diff\_RF_{it} + \beta_2^2 net\_buy_{it} + \beta_3^2 spread_{it} + \beta_4^2 spread\_stock_{it}$

$$+ \beta_5^2 dumy\_issue_{it} + \beta_6^2 cummulate\_created_{it} + \beta_7^2 Moneyness_{it} + \beta_8^2 Moneness_{it}^2 + \beta_{10}^2 \lambda_{it} + \varepsilon_{it}^2 \quad (23)$$

$$\varepsilon_{it}^2 = \alpha_1^2 + \eta_{it}^2$$

Model (3): $pricing\_error_{it} = \beta_0^3 + \beta_1^3 net\_buy_{it} + \beta_2^3 spread_{it} + \beta_3^3 spread\_stock_{it} + \beta_4^3 dumy\_issue_{it}$

$$+ \beta_5^3 cummulate\_created_{it} + \beta_6^3 Moneyness_{it} + \beta_7^3 Moneness_{it}^2 + \beta_{10}^3 \lambda_{it} + \varepsilon_{it}^3 \quad (24)$$

$$\varepsilon_{it}^3 = \alpha_1^3 + \eta_{it}^3$$

Where the definition of variables in the models are as following,

- *pricing_error*: warrants price deviations, which is defined as the difference between warrants price and theoretic price.
- *diff_RF*: defined as $R_t - f(S_t)$, that is, the difference between reference price for PT/MA investors and warrants theoretic price (here we adopt the GARCH model prices).
- *net_buy*: Net-buying pressure.
- *spread*: bid-ask spread of warrants.
- *spread_stock*: bid-ask spread of stocks.

- *turnover_warrant*: turnover of warrants.
- *turnover_stock*: turnover of underline stocks.
- *dumy_issue*: Dumy variable for warrants creation, equal to 1 if newly create, otherwise equal to 0.
- *cummulate_created*: natural logarithm of cumulated warrants creation.
- *Moneyness*: Moneyness, defined as stocks price divided by exercise price for call warrants, and exercise price divided by stock price for put warrants.
- $\lambda$: Dynamic AR(1) coefficient from regression model (20).

Because the sample period is long, so we need to check the stationarity for our panel data. **Table 4** shows the results based on Fisher-Type panel data unit root test. All of variables reject the hypothesis that all panel data include unit root. So we can regard our data as stationary panel data.

**Table 5** shows the results in which the warrants price deviations are calculated based on GARCH model. The results of **model 1** shows that the coefficients of Call Warrants turnover is not significant, and the coefficients of Put Warrants turnover is negative significant. These results are not consistent with our model (11). In summary, resell option theory can not explain put warrants price overvalued.

But Model (1) and model (2) show that PT/MA investor's reference price significantly positively correlated with warrants price deviation whether for call warrants or put warrants. The within or between $R^2$ of both model (1) and model (2) are relatively high, $R^2$ of put warrants is higher than call warrants'. Further more, comparing model (2) with model (3), we can see when we drop the reference price $R_F$ from the model, between $R^2$ decrease from

31.18% to 1.61% and Within $R^2$ decrease from 40.55% to 15.97% in the call warrants case; between $R^2$ decrease from 87.63% to 7.11% and Within $R^2$ decrease from 86.38% to 52.65% in the put warrants case. It means that reference price of PT/MA investors play the very important role in explaining warrants price deviations. To analyse how relatively important each variables are, we do variance analysis. **Table 6** shows that the reference price of PT/MA investors is most important variable in the models which can explain approximately 21.09% variation of price deviations in the call warrants and explain approximately 68.37% variation of price deviations in the put warrants.

From formula (19) and figure (5-8) we can see that the reference price of PT/MA investors basically depend on the cost for institutions to create the warrants. For the securities companies which create the call warrants, there is little risk with them because they have deposited enough underline assets to satisfy exercising from their counter parties. From the analysis in section 3.1 we know that as the stocks consistently going up, most of the reference prices are lower than the theoretic price of warrants, it leads to most of warrant market prices are undervalued. But the securities companies which issue the put warrants, they still have risk if their counter parties exercise warrants. Because they just deposit cash to buy the underline stocks when their counter party exercise, they might suffer loss when stock price is very low. So the reference price of institutions include the theoretic price of warrants and interest cost of cash margin. In the bull market, price keep going up, the theoretic price of put warrants are almost zero, in this case the interest cost become relatively important, as result, most of the market price of put warrants are overvalued.

Besides reference price and resell option, other variables also affect the price deviations. The proxy of underlying stocks' bubble $\lambda$ is positively significant correlated with pricing errors of Put Warrants. This result consistent with rational hedge hypothesis, but the $\lambda$ is also positively significant correlated with pricing errors of Call Warrants, it is not consistent with rational hedge hypothesis. So, the rational hedge hypothesis is mixed in our analysis.

The net-buying pressure of warrants positively and significantly correlated with its price deviations, But from **table 6**, it can explain only 0.01% of the price deviation for Call Warrants and 0.12% of the price deviation for Put Warrants.

Call warrants cumulated creation are significantly and negatively correlated with its price deviation, it means short sell can some how inhibit call warrants price. But from **table 6**, it can explain only 1.38% of the price deviation for Call Warrants and almost 0% for Put Warrants. On the other hand, put warrants cumulated creation are significantly and positively correlated with its price deviations. The result of which the coefficient of put warrants creation dummy variable is positive and significant also shows that the creation of put warrants can not only inhibit the high market price, but also drive the market price going up. Put warrants are deep out-of-the-money, its theoretic value is almost zero during a long period, so it is hardly used as hedge tools. The purpose for securities companies to create put warrants newly is not to inhibit its over price, but to make more money as put warrants price are overvalued. As a result, put warrants cumulated creation are positively and significantly correlated with price deviations.

**Table 7** and 8 shows the results based on BS model. They are almost consistent with the results based on GARCH model.

In summary, the reference price of PT/MA investor and call warrants are deep in-the-money, put warrants are deep out-of-the-money are main reasons which caused price deviations of Chinese warrants; The speculation behaviors from investor's heterogeneous beliefs also affect the price deviations, but it is not the most important reason.

## 4 Robustness

To check the robustness of our results, we carry out two test.

First, we change the reference prices. In former analyses, we use formula (19) to update the reference prices. Because the turnover of warrants are very big, the reference price maybe basically depend on the market price of last time. So, probably above analyses only capture the relationship between the present market prices and its lag prices. To avoid this problem, we keep the same reference price until next creation, that is, we do not update the reference price according to formula (19). These reference prices are written as $R\_F\_issuer$. **Table 9** and **Table 10** show the results for GARCH model and BS model respectively. We can see that even we only refer the created cost of issuers as the reference prices, and do not update it according to the turnover of warrants, the results are almost same.

Second, we take the first difference for all variables, and check the relationship among those variables at the first difference level. The results for GARCH model and BS model are shown in **Table 11** and **Table 12** respectively. For Call Warrants, the variations of reference prices are significantly positively correlated with variations of price deviations, but there is no significant correlation with the turnover of Warrants. However, for Put Warrants, the variations of reference prices are not significantly correlated with variations of price deviations, but there is significantly positively correlation with the turnover of Warrants.

In summary, for Call Warrants, reference prices play a important role to explain the variations of warrants price deviations, and the turnover of Warrants have no impact on the variations of warrants price deviations. However, for the Put Warrants, the turnover of Warrants play a important role to explain the variations of warrants price deviations, but reference prices do not have significant impact on it. As we see the descriptive statistics, we find the turnover of Put Warrants is much higher than the turnover of Call Warrants. This phenomena some how consistent with the results.

## 5 Conclusions

This paper do empirical studies about the price of deviations of Chinese covered warrants from the perspectives of warrants creation mechanism and investor's speculation behaviors using high frequent data. Our empirical studies show that:

- Call warrants are systematically under valued and put warrants are systematically over valued. For Call Warrants, the most important reason caused its large undervaluation is the special warrants creation mechanism of China. The institutions who issue Call Warrants need to deposit enough underline stocks into the special margin account to preparing the exercising by the counter parties. In other words, the issuers actually have hedge strategy, in the case where market persistently go up, the issuer can definitely make money. So they can accept relatively low price to issue. We find reference prices play a important role to explain the variations of warrants price deviations, and the turnover of Warrants do not. So the prospect theory dominate the resell option theory in explaining the under valuation of Call Warrants. On the other hand, the turnover of Warrants play a important role to explain the variations of warrants price deviations, but the reference prices do not. So, the resell option theory dominate the prospect theory in explaining the over valuation of Put Warrants. This result consistent with Xiong and Yu (2011).

- The mechanism that newly created warrants must keep the same exercise price as original warrants make warrants become the tools for speculation. Because the exercise price of warrants can not be changed but the underline stock's price boomed, so it causes put warrants being deep out-of-the-money and call warrants being deep in-the-money. the put warrants which are deep out-of-the-money are almost zero theoretic value, finally they become the object of speculation.

- The strict warrants creation qualified requirement give the securities companies special rights, this make the issuer have absolute bargaining power. The creation of put warrants not only can't inhibit the high market price, but also boom the price. Because the issuer choose the timing when put warrants are booming to create new put warrants. The speculation behavior from heterogeneous beliefs of investors affect warrants price deviations significantly, but it can explain only small parts of the price deviations.

- The creation of call warrants can some what inhibit call warrants price, but the strict creation requirements limit the effects of short sell.

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Table1 Description Statistics of the Panel Data Variables for the Call Warrants

| Variable | | Mean | Std. Dev. | Min | Max |
|---|---|---|---|---|---|
| pricing_error_garch | overall | -2.0328 | 1.2062 | -7.2039 | 2.1702 |
| | between | | 1.2882 | -4.2407 | -0.4264 |
| | within | | 0.5202 | -4.9960 | 2.5992 |
| Pricing_error_BS | overall | -2.0504 | 1.2088 | -7.2074 | 2.1198 |
| | between | | 1.2908 | -4.2667 | -0.4279 |
| | within | | 0.5162 | -4.9910 | 2.5922 |
| garch_option_price | overall | 5.1634 | 4.3828 | 1.2017 | 25.8075 |
| | between | | 3.8237 | 2.2513 | 14.0686 |
| | within | | 1.9717 | -0.5370 | 16.9024 |
| BS_formual_price | overall | 5.1810 | 4.3899 | 1.3265 | 25.8328 |
| | between | | 3.8259 | 2.2563 | 14.0946 |
| | within | | 1.9815 | -0.5451 | 16.9191 |
| diff_RF | overall | -2.6070 | 1.8894 | -14.2649 | 0.1131 |
| | between | | 2.0152 | -6.1690 | -0.5570 |
| | within | | 0.9929 | -11.2437 | 3.1343 |
| diff_RF_issuer | overall | -4.3853 | 3.3031 | -21.8970 | -1.0830 |
| | between | | 2.7735 | -10.1577 | -1.8736 |
| | within | | 1.9692 | -16.1246 | 1.3148 |
| net-buying | overall | 0.0177 | 0.0539 | -0.1439 | 0.4804 |
| | between | | 0.0139 | 0.0006 | 0.0407 |
| | within | | 0.0519 | -0.1669 | 0.4574 |
| spread | overall | 0.0026 | 0.0059 | 0.0003 | 0.0403 |
| | between | | 0.0041 | 0.0004 | 0.0131 |
| | within | | 0.0039 | -0.0075 | 0.0299 |
| spread_stock | overall | 0.0034 | 0.0056 | 0.0000 | 0.0400 |
| | between | | 0.0036 | 0.0015 | 0.0126 |
| | within | | 0.0040 | -0.0083 | 0.0308 |
| turnover_warrant | overall | 0.4360 | 1.5887 | 0.0012 | 49.8144 |
| | between | | 0.4713 | 0.0072 | 1.3234 |
| | within | | 1.5032 | -0.6550 | 49.3656 |
| turnover_stock | overall | 0.0165 | 0.0164 | 0.0014 | 0.1591 |
| | between | | 0.0075 | 0.0095 | 0.0325 |
| | within | | 0.0145 | -0.0130 | 0.1430 |
| dumy_issue | overall | 0.0726 | 0.2596 | 0.0000 | 1.0000 |
| | between | | 0.0919 | 0.0000 | 0.2667 |
| | within | | 0.2485 | -0.1941 | 1.0621 |
| Cumulate_created | overall | 19.4541 | 0.9827 | 17.8511 | 20.8328 |
| | between | | 0.9131 | 17.8910 | 20.7989 |
| | within | | 0.0379 | 19.1582 | 19.5435 |
| Moneyness | overall | 1.4679 | 0.9424 | 0.5158 | 5.9085 |
| | between | | 0.7639 | 0.5854 | 3.2338 |
| | within | | 0.5226 | -0.1682 | 4.1426 |
| $\lambda$ | overall | 1.0014 | 0.0034 | 0.9923 | 1.0190 |
| | between | | 0.0016 | 0.9989 | 1.0044 |
| | within | | 0.0030 | 0.9921 | 1.0160 |

**Note:** Pricing_error_garch is the warrants price deviations based on Garch option pricing model;

pricing_error_BS is the warrants price deviations based on BS model; garch_option_price is the warrants theoretic price based on Garch option pricing model; BS_formual_price is the warrants theoretic price based on BS model; diff_RF is the difference between the reference price of PT/MA investors and the Garch model theoretic price; diff_RF_issuer is the difference between the reference price of PT/MA investors and the Garch model theoretic price, but the reference prices keep the same value of the reference price at last creation date until the next creation date; net_buy is the net-buying pressure; spread is the bid-ask spread of warrants; spread_stock is the bid-ask spread of stocks; turnover_warrant is the daily turnover of warrants; turnover_stock is the daily turnover of stocks; dumy_issue is the dumy variable of creation, it equals 1 when create warrants, otherwise it equals 0; cummulate_created is warrants cumulated creation; Moneyness equals the ratio of the stock price to exercise price for call warrants, and equals the ratio of exercise price to stock price for put warrants; $\lambda$ is dynamic AR(1) regression coefficient from model (20).

Table2 Description Statistics of the Panel Data Variables for the Put Warrants

| Variable | | Mean | Std. Dev. | Min | Max |
|---|---|---|---|---|---|
| pricing_error_garch | overall | 1.1729 | 0.9169 | 0.1790 | 5.7736 |
| | between | | 0.8556 | 0.4012 | 3.8737 |
| | within | | 0.3584 | -0.9857 | 3.8425 |
| Pricing_error_BS | overall | 1.1277 | 0.8838 | -0.0637 | 5.7665 |
| | between | | 0.7970 | 0.4009 | 3.6193 |
| | within | | 0.4080 | -1.3034 | 3.8063 |
| garch_option_price | overall | 0.0010 | 0.0056 | 0.0000 | 0.1075 |
| | between | | 0.0012 | 0.0000 | 0.0033 |
| | within | | 0.0054 | -0.0024 | 0.1058 |
| BS_formual_price | overall | 0.0462 | 0.1562 | 0.0000 | 1.6472 |
| | between | | 0.0705 | 0.0000 | 0.2574 |
| | within | | 0.1401 | -0.2112 | 1.4360 |
| diff_RF | overall | 1.1859 | 0.9338 | 0.0356 | 5.5140 |
| | between | | 0.8772 | 0.4017 | 3.9526 |
| | within | | 0.3567 | -2.1891 | 3.8471 |
| diff_RF_issuer | overall | 0.1297 | 0.1306 | -0.0838 | 0.6860 |
| | between | | 0.1036 | 0.0306 | 0.4234 |
| | within | | 0.0833 | -0.2497 | 0.3923 |
| net-buying | overall | 0.0203 | 0.0648 | -0.1569 | 0.7890 |
| | between | | 0.0097 | 0.0027 | 0.0386 |
| | within | | 0.0639 | -0.1557 | 0.7956 |
| spread | overall | 0.0005 | 0.0004 | 0.0002 | 0.0045 |
| | between | | 0.0002 | 0.0002 | 0.0008 |
| | within | | 0.0004 | -0.0001 | 0.0041 |
| spread_stock | overall | 0.0047 | 0.0083 | 0.0000 | 0.0780 |
| | between | | 0.0057 | 0.0003 | 0.0202 |
| | within | | 0.0058 | -0.0148 | 0.0625 |
| turnover_warrant | overall | 0.7548 | 0.9809 | 0.0349 | 14.0975 |
| | between | | 0.2935 | 0.3145 | 1.2289 |
| | within | | 0.9424 | -0.3701 | 14.4052 |

| | | | | | |
|---|---|---|---|---|---|
| turnover_stock | overall | 0.0176 | 0.0158 | 0.0011 | 0.1591 |
| | between | | 0.0072 | 0.0084 | 0.0320 |
| | within | | 0.0138 | -0.0113 | 0.1447 |
| dumy_issue | overall | 0.0459 | 0.2093 | 0.0000 | 1.0000 |
| | between | | 0.0475 | 0.0000 | 0.1250 |
| | within | | 0.2043 | -0.0791 | 1.0303 |
| Cumulate_created | overall | 19.9159 | 0.6486 | 18.6030 | 21.6477 |
| | between | | 0.7194 | 18.6030 | 21.5397 |
| | within | | 0.0483 | 19.7425 | 20.0878 |
| Moneyness | overall | 0.8221 | 0.3147 | 0.1630 | 1.4932 |
| | between | | 0.2537 | 0.4269 | 1.2859 |
| | within | | 0.1496 | 0.1424 | 1.2135 |
| $\lambda$ | overall | 1.0020 | 0.0037 | 0.9938 | 1.0190 |
| | between | | 0.0017 | 0.9989 | 1.0044 |
| | within | | 0.0034 | 0.9927 | 1.0166 |

**Note:** Pricing_error_garch is the warrants price deviations based on Garch option pricing model; pricing_error_BS is the warrants price deviations based on BS model; garch_option_price is the warrants theoretic price based on Garch option pricing model; BS_formual_price is the warrants theoretic price based on BS model; diff_RF is the difference between the reference price of PT/MA investors and the Garch model theoretic price; diff_RF_issuer is the difference between the reference price of PT/MA investors and the Garch model theoretic price, but the reference prices keep the same value of the reference price at last creation date until the next creation date; net_buy is the net-buying pressure; spread is the bid-ask spread of warrants; spread_stock is the bid-ask spread of stocks; turnover_warrant is the daily turnover of warrants; turnover_stock is the daily turnover of stocks; dumy_issue is the dumy variable of creation, it equals 1 when create warrants, otherwise it equals 0; cummulate_created is warrants cumulated creation; Moneyness equals the ratio of the stock price to exercise price for call warrants, and equals the ratio of exercise price to stock price for put warrants; $\lambda$ is dynamic AR(1) regression coefficient from model (20).

Table3 The Differences Between Call and Put Warrants

| Warrant Type | Statistics | Pricing error GARCH model | Pricing error BS model | option price GARCH model | Option price BS model | diff_RF | diff_RF_issuer |
|---|---|---|---|---|---|---|---|
| Call Warrants | observation | 1240 | 1240 | 1240 | 1240 | 1240 | 1240 |
| | Mean | -2.0328 | -2.0504 | 5.1634 | 5.1810 | -2.6070 | -4.3853 |
| | Std. | (1.2062) | (1.2088) | (4.3828) | (4.3899) | (1.8894) | (3.3031) |
| | Median | [-1.7675] | [-1.7895] | [3.7395] | [3.7543] | [-1.8855] | [-3.5206] |
| Put Warrants | observation | 2179 | 2179 | 2179 | 2179 | 2179 | 2179 |
| | Mean | 1.1729 | 1.1277 | 0.0010 | 0.0462 | 1.1859 | 0.1297 |
| | Std. | (0.9169) | (0.8838) | (0.0056) | (0.1562) | (0.9338) | (0.1306) |
| | Median | [0.8627] | [0.8370] | [0.0000] | [0.0023] | [0.8729] | [0.0908] |
| Mean Difference | | -3.2057*** | -3.1780*** | 5.1624*** | 5.1347*** | -3.7929*** | -4.5149*** |
| | | (0.0395) | (0.0392) | (0.1245) | (0.1247) | (0.0573) | (0.0938) |
| Warrant Type | Statistics | net-buying | spread | Spread_stock | Turnover warrant | Turnover stock | dumy_issuer |
| Call Warrants | observation | 1240 | 1240 | 1240 | 1240 | 1240 | 1240 |
| | Mean | 0.0177 | 0.0026 | 0.0034 | 0.4360 | 0.0165 | 0.0726 |
| | Std. | (0.0539) | (0.0059) | (0.0056) | (1.5887) | (0.0164) | (0.2596) |
| | Median | [0.0032] | [0.0008] | [0.0019] | [0.0844] | [0.0115] | [0.0000] |
| Put Warrants | observation | 2179 | 2179 | 2179 | 2179 | 2179 | 2179 |
| | Mean | 0.0203 | 0.0005 | 0.0047 | 0.7548 | 0.0176 | 0.0459 |
| | Std. | (0.0648) | (0.0004) | (0.0083) | (0.9809) | (0.0158) | (0.2093) |
| | Median | [0.0041] | [0.0004] | [0.0019] | [0.4433] | [0.0127] | [0.0000] |
| Mean Difference | | -0.0026*** | 0.0021*** | -0.0013*** | -0.3188*** | -0.0011** | 0.0267*** |
| | | (0.0021) | (0.0002) | (0.0002) | (0.0498) | (0.0006) | (0.0086) |
| Warrant Type | Statistics | Cumulate created | Moneyness | $\text{Moneyness}^2$ | $\lambda$ | | |
| Call Warrants | observation | 1240 | 1240 | 1240 | 1240 | | |
| | Mean | 19.4541 | 1.4679 | 3.0420 | 1.0014 | | |
| | Std. | (0.9827) | (0.9424) | (5.3312) | (0.0034) | | |
| | Median | [19.3242] | [1.2041] | [1.4498] | [1.0010] | | |
| Put Warrants | observation | 2179 | 2179 | 2179 | 2179 | | |
| | Mean | 19.9159 | 0.8221 | 0.7749 | 1.0020 | | |
| | Std. | (0.6486) | (0.3147) | (0.4894) | (0.0037) | | |
| | Median | [19.8970] | [0.9023] | [0.8142] | [1.0013] | | |
| Mean Difference | | -0.4618*** | 0.6457*** | 2.2671*** | -0.0006*** | | |
| | | (0.0312) | (0.0276) | (0.1518) | (0.0001) | | |

Table 4 Unit Root Test of Panel Data

| Variables | P Statistic | p-value |
|---|---|---|
| pricing_error_garch | 116.3553 | 0 |
| pricing_error_bs | 113.7476 | 0 |
| diff_RF | 145.0968 | 0 |
| diff_RF_issuer | 118.8327 | 0 |
| net_buy | 391.7900 | 0 |
| spread | 201.3692 | 0 |
| spread_stock | 205.6551 | 0 |
| turnover_warrant | 191.5422 | 0 |
| turnover_stock | 167.3234 | 0 |
| cummulate created | 246.7644 | 0 |
| $\lambda$ | 142.6550 | 0 |

**Note:** This table shows the results of Fisher-Type unit root test for panel data based on Aaugmented Dickey-Fuller. Null Hypothesis: there are unit roots in all panel data.

Table 5 Panel Data Analysis Results (GARCH)

| pricing_errors | Call | | | Put | | |
|---|---|---|---|---|---|---|
| | Model 1 | Model 2 | Model 3 | Model 1 | Model 2 | Model 3 |
| diff_RF | 0.4241*** | 0.4244*** | | 0.6659*** | 0.6759*** | |
| | (0.0190) | (0.0189) | | (0.0144) | (0.0143) | |
| net_buy | 0.9272*** | 0.9638*** | 0.9969*** | 0.5935*** | 0.4963*** | 0.1166 |
| | (0.2333) | (0.2212) | (0.2629) | (0.0757) | (0.0640) | (0.0908) |
| spread | 9.0407 | 8.9896 | -5.4667 | 188.1818*** | 172.2131*** | 547.9982*** |
| | (7.1554) | (7.1305) | (8.4393) | (14.2967) | (13.6134) | (15.8102) |
| spread_stock | -30.6613*** | -30.6543*** | -58.8039*** | -6.5242*** | -6.5217*** | -18.5929*** |
| | (5.1722) | (5.1639) | (5.9536) | (0.7833) | (0.7822) | (1.0566) |
| turnover_warrant | 0.0043 | | | -0.0156*** | | |
| | (0.0079) | | | (0.0058) | | |
| turn_over | 0.1269 | | | 1.2054*** | | |
| | (0.9320) | | | (0.2830) | | |
| dumy_issue | 0.1403*** | 0.1407*** | 0.0874 | 0.0602*** | 0.0629*** | 0.0820*** |
| | (0.0472) | (0.0471) | (0.0559) | (0.0183) | (0.0183) | (0.0262) |
| cummulatecreated | -0.8361** | -0.8455*** | -1.0287*** | 0.2332*** | 0.2192** | 0.6438*** |
| | (0.3292) | (0.3245) | (0.3855) | (0.0854) | (0.0859) | (0.1220) |
| moneyness | -0.6036*** | -0.6047*** | -0.5876*** | -0.3845*** | -0.3413*** | -1.0480*** |
| | (0.1119) | (0.1100) | (0.1307) | (0.0906) | (0.0880) | (0.1239) |
| $Moneyness^2$ | 0.1428*** | 0.1429*** | 0.1132*** | 0.4500*** | 0.4234*** | 0.9804*** |
| | (0.0169) | (0.0167) | (0.0198) | (0.0605) | (0.0601) | (0.0842) |
| $\lambda$ | 39.2111*** | 39.5140*** | -5.7555 | 6.9227*** | 8.4728*** | 9.4143*** |
| | (5.3181) | (4.9665) | (5.3952) | (1.3845) | (1.3567) | (1.9380) |
| Constant | -23.4266*** | -23.5409*** | 24.4524** | -11.3191*** | -12.6013*** | -21.1750*** |
| | (8.4753) | (8.4271) | (9.6881) | (2.0790) | (2.0724) | (2.9495) |
| Warrants Fixed | Yes | Yes | Yes | Yes | Yes | Yes |
| Observation | 1240 | 1240 | 1240 | 2179 | 2179 | 2179 |
| Between $R^2$ | 0.3175 | 0.3118 | 0.0161 | 0.8585 | 0.8763 | 0.0711 |
| Within $R^2$ | 0.4057 | 0.4055 | 0.1597 | 0.7709 | 0.8638 | 0.5265 |

**Note:** The t statistics are given in parenthesis, *, **, *** show 10%、5%、1% statistic significant respectively. The dependent variable is the warrants price deviations based on GARCH option pricing model. The independent variables are as following: diff_RF is the difference between the reference price of PT/MA investors and the Garch model theoretic price; net_buy is the net-buying pressure; spread is the bid-ask spread of warrants; spread_stock is the bid-ask spread of stocks; turnover_warrant is the daily turnover of warrants; turnover_stock is the daily turnover of stocks; dumy_issue is the dumy variable of creation, it equals 1 when create warrants, otherwise it equals 0; cummulate_created shows warrants cumulated creation; Moneyness equals the ratio of the stock price to exercise price for call warrants, and equals the ratio of exercise price to stock price for put warrants; $\lambda$ is dynamic AR(1) regression coefficient from model (20).

Table 6 Variance Analysis of The Factors Affecting Warrants Price Deviations (GARCH)

| variables | call | put | variables | call | put |
|---|---|---|---|---|---|
| diff_RF | 21.09% | 68.37% | diff_RF_issuer | 7.49% | 41.20% |
| net_buy | 0.01% | 0.12% | net_buy | 0.01% | 0.11% |
| spread | 0.01% | 0.01% | spread | 0.06% | 2.42% |
| spread_stock | 0.46% | 0.00% | spread_stock | 0.79% | 5.85% |
| turnover_warrant | 0.03% | 0.00% | turnover_warrant | 0.01% | 0.00% |
| turnover_stock | 0.37% | 0.00% | turnover_stock | 1.64% | 0.00% |
| dumy_issue | 0.26% | 0.01% | dumy_issue | 0.15% | 0.59% |
| cummulatecreated | 1.38% | 0.00% | cummulatecreated | 1.77% | 0.83% |
| moneyness | 3.28% | 0.00% | moneyness | 16.92% | 1.60% |
| $\text{Moneyness}^2$ | 3.64% | 0.00% | $\text{Moneyness}^2$ | 14.46% | 1.52% |
| $\lambda$ | 1.27% | 0.01% | $\lambda$ | 0.40% | 0.06% |
| Residual | 15.41% | 4.33% | Residual | 29.02% | 31.50% |
| Total | 100.00% | 100.00% | Total | 100.00% | 100.00% |

**Note:** diff_RF is the difference between the reference price of PT/MA investors and the Garch model theoretic price; diff_RF_issuer is the difference between the reference price of PT/MA investors and the Garch model theoretic price, but the reference prices keep the same value of the reference price at last creation date until the next creation date; net_buy is the net-buying pressure; spread is the bid-ask spread of warrants; spread_stock is the bid-ask spread of stocks; turnover_warrant is the daily turnover of warrants; turnover_stock is the daily turnover of stocks; dumy_issue is the dumy variable of creation, it equals 1 when create warrants, otherwise it equals 0; cummulate_created shows warrants cumulated creation; Moneyness equals the ratio of the stock price to exercise price for call warrants, and equals the ratio of exercise price to stock price for put warrants; $\lambda$ is dynamic AR(1) regression coefficient from model (20).

Table 7 Panel Data Analysis Results (BS)

| pricing_errors | Call | | | Put | | |
|---|---|---|---|---|---|---|
| | Model 1 | Model 2 | Model 3 | Model 1 | Model 2 | Model 3 |
| diff_RF | 0.4117*** | 0.4123*** | | 0.7498*** | 0.7549*** | |
| | (0.0191) | (0.0190) | | (0.0127) | (0.0126) | |
| net_buy | 0.9255*** | 0.9663*** | 0.9996*** | 0.6028*** | 0.5486*** | 0.1489 |
| | (0.2318) | (0.2197) | (0.2585) | (0.0778) | (0.0656) | (0.1066) |
| spread | 7.5264 | 7.4191 | -7.4325 | 143.2763*** | 133.5241*** | 569.4204*** |
| | (7.1123) | (7.0881) | (8.3008) | (14.1091) | (13.4805) | (18.5694) |
| spread_stock | -30.6917*** | -30.7083*** | -57.5206*** | -6.2576*** | -6.3358*** | -23.5933*** |
| | (5.1362) | (5.1280) | (5.8558) | (0.8139) | (0.8117) | (1.2409) |
| turnover_warrant | 0.0042 | | | -0.0092 | | |
| | (0.0079) | | | (0.0059) | | |
| turn_over | 0.2270 | | | 1.1237*** | | |
| | (0.9261) | | | (0.2910) | | |
| dumy_issue | 0.1386*** | 0.1392*** | 0.0875 | 0.0485*** | 0.0516*** | 0.0452 |
| | (0.0469) | (0.0468) | (0.0550) | (0.0188) | (0.0188) | (0.0308) |
| cummulatecreated | -0.7856** | -0.8008** | -0.9437** | 0.1228 | 0.1125 | 0.4109*** |
| | (0.3270) | (0.3223) | (0.3792) | (0.0875) | (0.0878) | (0.1433) |
| moneyness | -0.6659*** | -0.6648*** | -0.6908*** | -0.1662* | -0.1515* | -0.6104*** |
| | (0.1112) | (0.1093) | (0.1286) | (0.0919) | (0.0894) | (0.1455) |
| $Moneyness^2$ | 0.1492*** | 0.1491*** | 0.1252*** | 0.3510*** | 0.3368*** | 0.8927*** |
| | (0.0168) | (0.0166) | (0.0195) | (0.0616) | (0.0612) | (0.0989) |
| $\lambda$ | 37.9052*** | 38.4112*** | -5.4202 | 8.3748*** | 9.6020*** | 14.4712*** |
| | (5.2932) | (4.9417) | (5.3067) | (1.4242) | (1.3949) | (2.2762) |
| Constant | -23.0694*** | -23.2751*** | 22.5600** | -10.7709*** | -11.7829*** | -21.9262*** |
| | (8.4180) | (8.3697) | (9.5290) | (2.1376) | (2.1260) | (3.4642) |
| Warrants Fixed | Yes | Yes | Yes | Yes | Yes | Yes |
| Observation | 1240 | 1240 | 1240 | 2179 | 2179 | 2179 |
| Between $R^2$ | 0.3575 | 0.3467 | 0.0034 | 0.9255 | 0.9356 | 0.1594 |
| Within $R^2$ | 0.4042 | 0.4041 | 0.1744 | 0.8130 | 0.8114 | 0.4960 |

**Note:** The t statistics are given in parenthesis, *, **, *** show 10%、5%、1% statistic significant respectively. The dependent variable is the warrants price deviations based on BS option pricing model. The independent variables are as following: diff_RF is the difference between the reference price of PT/MA investors and the Garch model theoretic price; net_buy is the net-buying pressure; spread is the bid-ask spread of warrants; spread_stock is the bid-ask spread of stocks; turnover_warrant is the daily turnover of warrants; turnover_stock is the daily turnover of stocks; dumy_issue is the dumy variable of creation, it equals 1 when create warrants, otherwise it equals 0; cummulate_created shows warrants cumulated creation; Moneyness equals the ratio of the stock price to exercise price for call warrants, and equals the ratio of exercise price to stock price for put warrants; $\lambda$ is dynamic AR(1) regression coefficient from model (13).

Table 8 Variance Analysis of The Factors Affecting Warrants Price Deviations (BS)

| variables | call | put | variables | call | put |
|---|---|---|---|---|---|
| diff_RF_BS | 20.52% | 73.04% | diff_RF_issuer | 7.11% | 21.79% |
| net_buy | 0.01% | 0.13% | net_buy | 0.01% | 0.15% |
| spread | 0.02% | 0.01% | spread | 0.06% | 3.62% |
| spread_stock | 0.45% | 0.00% | spread_stock | 0.78% | 14.46% |
| turnover_warrant | 0.03% | 0.00% | turnover_warrant | 0.01% | 0.41% |
| turnover_stock | 0.38% | 0.00% | turnover_stock | 1.67% | 0.11% |
| dumy_issue | 0.27% | 0.01% | dumy_issue | 0.16% | 0.40% |
| cummulatecreated | 1.34% | 0.00% | cummulatecreated | 1.71% | 2.68% |
| moneyness | 3.28% | 0.00% | moneyness | 16.70% | 0.83% |
| $Moneyness^2$ | 3.60% | 0.00% | $Moneyness^2$ | 14.01% | 0.49% |
| $\lambda$ | 1.22% | 0.01% | $\lambda$ | 0.37% | 0.60% |
| Residual | 15.34% | 4.66% | Residual | 28.76% | 55.91% |
| Total | 100.00% | 100.00% | Total | 100.00% | 100.00% |

**Note:** diff_RF is the difference between the reference price of PT/MA investors and the Garch model theoretic price; diff_RF_issuer is the difference between the reference price of PT/MA investors and the Garch model theoretic price, but the reference prices keep the same value of the reference price at last creation date until the next creation date; net_buy is the net-buying pressure; spread is the bid-ask spread of warrants; spread_stock is the bid-ask spread of stocks; turnover_warrant is the daily turnover of warrants; turnover_stock is the daily turnover of stocks; dumy_issue is the dumy variable of creation, it equals 1 when create warrants, otherwise it equals 0; cummulate_created shows warrants cumulated creation; Moneyness equals the ratio of the stock price to exercise price for call warrants, and equals the ratio of exercise price to stock price for put warrants; $\lambda$ is dynamic AR(1) regression coefficient from model (13).

Table 9 Panel Data Analysis Results (GARCH)

| pricing_errors | Call | | | Put | | |
|---|---|---|---|---|---|---|
| | Model 1 | Model 2 | Model 3 | Model 1 | Model 2 | Model 3 |
| diff_RF_issuer | 0.3944*** | 0.3946*** | | 0.8316*** | 0.8161*** | |
| | (0.0332) | (0.0332) | | (0.0926) | (0.0944) | |
| net_buy | 0.9404*** | 1.0728*** | 0.9969*** | 0.5183*** | 0.0894 | 0.1166 |
| | (0.2623) | (0.2491) | (0.2629) | (0.1049) | (0.0893) | (0.0908) |
| spread | 18.1755** | 16.8986** | -5.4667 | 574.0557*** | 537.5410*** | 547.9982*** |
| | (8.2327) | (8.2123) | (8.4393) | (15.9047) | (15.5937) | (15.8102) |
| spread_stock | -37.8947*** | -38.5805*** | -58.8039*** | -14.7427*** | -14.8758*** | -18.5929*** |
| | (5.8979) | (5.8904) | (5.9536) | (1.1074) | (1.1244) | (1.0566) |
| turnover_warrant | 0.0045 | | | -0.0613*** | | |
| | (0.0089) | | | (0.0079) | | |
| turn_over | 2.0572** | | | 1.9332*** | | |
| | (1.0431) | | | (0.3916) | | |
| dumy_issue | 0.0967* | 0.1028* | 0.0874 | 0.0945*** | 0.0974*** | 0.0820*** |
| | (0.0530) | (0.0529) | (0.0559) | (0.0254) | (0.0258) | (0.0262) |
| Cumulate_created | -0.4111 | -0.5333 | -1.0287*** | 0.4812*** | 0.4795*** | 0.6438*** |
| | (0.3723) | (0.3675) | (0.3855) | (0.1192) | (0.1215) | (0.1220) |
| moneyness | -0.7547*** | -0.7165*** | -0.5876*** | -1.8087*** | -1.6174*** | -1.0480*** |
| | (0.1262) | (0.1243) | (0.1307) | (0.1392) | (0.1385) | (0.1239) |
| $Moneyness^2$ | 0.2990*** | 0.2945*** | 0.1132*** | 1.2883*** | 1.2087*** | 0.9804*** |
| | (0.0244) | (0.0242) | (0.0198) | (0.0859) | (0.0869) | (0.0842) |
| lambda | 9.3419* | 13.1459*** | -5.7555 | 4.2743** | 8.1494*** | 9.4143*** |
| | (5.6780) | (5.3522) | (5.3952) | (1.9240) | (1.9113) | 1.9380 |
| Constant | -1.4403 | -2.8754 | 24.4524** | -12.5349*** | -16.4611*** | -21.1750 |
| | (9.4798) | (9.4603) | (9.6881) | (2.9258) | (2.9511) | (2.9495) |
| Warrants Fixed | Yes | Yes | Yes | Yes | Yes | Yes |
| Observation | 1240 | 1240 | 1240 | 2179 | 2179 | 2179 |
| Between $R^2$ | 0.5275 | 0.4249 | 0.1597 | 0.0007 | 0.0020 | 0.0711 |
| Within $R^2$ | 0.2492 | 0.2467 | 0.0161 | 0.5600 | 0.5424 | 0.5265 |

**Note:** The t statistics are given in parenthesis, *, **, *** show 10%、5%、1% statistic significant respectively. The dependent variable is the warrants price deviations based on GARCH option pricing model. The independent variables are as following: diff_RF is the difference between the reference price of PT/MA investors and the Garch model theoretic price; diff_RF_issuer is the difference between the reference price of PT/MA investors and the Garch model theoretic price, but the reference prices keep the same value of the reference price at last creation date until the next creation date; net_buy is the net-buying pressure; spread is the bid-ask spread of warrants; spread_stock is the bid-ask spread of stocks; turnover_warrant is the daily turnover of warrants; turnover_stock is the daily turnover of stocks; dumy_issue is the dumy variable of creation, it equals 1 when create warrants, otherwise it equals 0; cummulate_created shows warrants cumulated creation; Moneyness equals the ratio of the stock price to exercise price for call warrants, and equals the ratio of exercise price to stock price for put warrants; $\lambda$ is dynamic AR(1) regression coefficient from model (20).

Table 10 Panel Data Analysis Results (BS)

| pricing_errors | Call | | | Put | | |
|---|---|---|---|---|---|---|
| | Model 1 | Model 2 | Model 3 | Model 1 | Model 2 | Model 3 |
| diff_RF_issuer | 0.3606*** | 0.3610*** | | 0.9887*** | 0.9840*** | |
| | (0.0341) | (0.0342) | | (0.0319) | (0.0325) | |
| net_buy | 0.9331*** | 1.0681*** | 0.9996*** | 0.5151*** | 0.0843 | 0.1489 |
| | (0.2608) | (0.2477) | (0.2585) | (0.1050) | (0.0894) | (0.1066) |
| spread | 15.0341* | 13.7382* | -7.4325 | 572.4145*** | 535.7327*** | 569.4204*** |
| | (8.2166) | (8.1976) | (8.3008) | (15.9102) | (15.5993) | (18.5694) |
| spread_stock | -38.7886*** | -39.4824*** | -57.5206*** | -14.0849*** | -14.1911*** | -23.5933*** |
| | (5.8683) | (5.8617) | (5.8558) | (1.0689) | (1.0852) | (1.2409) |
| turnover_warrant | 0.0045 | | | -0.0615*** | | |
| | (0.0088) | | | (0.0079) | | |
| turn_over | 2.1037** | | | 1.9351*** | | |
| | (1.0372) | | | (0.3919) | | |
| dumy_issue | 0.0953* | 0.1016* | 0.0875 | 0.0971*** | 0.1000*** | 0.0452 |
| | (0.0527) | (0.0526) | (0.0550) | (0.0254) | (0.0259) | (0.0308) |
| cummulatecreated | -0.3964 | -0.5212 | -0.9437** | 0.4469*** | 0.4419*** | 0.4109*** |
| | (0.3700) | (0.3653) | (0.3792) | (0.1178) | (0.1201) | (0.1433) |
| moneyness | -0.8106*** | -0.7714*** | -0.6908*** | -1.9141*** | -1.7275*** | -0.6104*** |
| | (0.1252) | (0.1233) | (0.1286) | (0.1285) | (0.1274) | (0.1455) |
| $Moneyness^2$ | 0.2912*** | 0.2868*** | 0.1252*** | 1.3316*** | 1.2543*** | 0.8927*** |
| | (0.0243) | (0.0241) | (0.0195) | (0.0828) | (0.0837) | (0.0989) |
| lambda | 7.8536 | 11.7508** | -5.4202 | 4.0782** | 7.9702*** | 14.4712*** |
| | (5.6592) | (5.3353) | (5.3067) | (1.9316) | (1.9193) | (2.2762) |
| Constant | -0.2795 | -1.7578 | 22.5600** | -11.6250*** | -15.5032*** | -21.9262*** |
| | (9.4299) | (9.4109) | (9.5290) | (2.8852) | (2.9105) | (3.4642) |
| Warrants Effect | Yes | Yes | Yes | Yes | Yes | Yes |
| Observation | 1240 | 1240 | 1240 | 2179 | 2179 | 2179 |
| Between $R^2$ | 0.5754 | 0.4610 | 0.0034 | 0.0122 | 0.0161 | 0.1594 |
| Within $R^2$ | 0.2462 | 0.2435 | 0.1744 | 0.6600 | 0.6463 | 0.4960 |

**Note:** The t statistics are given in parenthesis, *, **, *** show 10%、5%、1% statistic significant respectively. The dependent variable is the warrants price deviations based on BS option pricing model. The independent variables are as following: diff_RF is the difference between the reference price of PT/MA investors and the Garch model theoretic price; diff_RF_issuer is the difference between the reference price of PT/MA investors and the Garch model theoretic price, but the reference prices keep the same value of the reference price at last creation date until the next creation date; net_buy is the net-buying pressure; spread is the bid-ask spread of warrants; spread_stock is the bid-ask spread of stocks; turnover_warrant is the daily turnover of warrants; turnover_stock is the daily turnover of stocks; dumy_issue is the dumy variable of creation, it equals 1 when create warrants, otherwise it equals 0; cummulate_created shows warrants cumulated creation; Moneyness equals the ratio of the stock price to exercise price for call warrants, and equals the ratio of exercise price to stock price for put warrants; $\lambda$ is dynamic AR(1) regression coefficient from model (20).

Table 11 Panel Data Analysis Results (At First Deference Level, Garch)

| delta_pricing_error_garch | Call | Put | delta_pricing_error_garch | Call | Put |
|---|---|---|---|---|---|
| delta_diff_RF | 0.1077*** | 0.0018 | delta_diff_RF_issuer | 0.2804*** | -0.2267 |
| | (0.0196) | (0.0147) | | (0.0259) | (0.1825) |
| delta_spread_warrant | -6.1236 | 35.5630* | delta_spread_warrant | -12.5467* | 37.3798* |
| | (7.0050) | (20.3713) | | (6.8056) | (20.1903) |
| delta_spread_stock | 10.2777** | -0.5052 | delta_spread_stock | 7.4587 | -0.5451 |
| | (4.8605) | (1.1071) | | (4.7093) | (1.1071) |
| delta_turnover_warrant | 0.0030 | 0.0296*** | delta_turnover_warrant | 0.0025 | 0.0295*** |
| | (0.0029) | (0.0028) | | (0.0028) | (0.0028) |
| delta_turnover_stock | -0.0562 | 0.3668** | delta_turnover_stock | -0.2660 | 0.3612* |
| | (0.4955) | (0.1855) | | (0.4796) | (0.1855) |
| delta_lambda | 12.7083 | -0.0983 | delta_lambda | 40.6763*** | -0.1725 |
| | (7.8547) | (2.5208) | | (8.0586) | (2.5203) |
| constant | 0.0003 | -0.0066*** | constant | 0.0046 | -0.0068*** |
| | (0.0057) | (0.0020) | | (0.0056) | (0.0021) |
| Warrants Effect | Yes | Yes | Warrants Effect | Yes | Yes |
| observation | 1231 | 2165 | observation | 1231 | 2165 |
| Between $R^2$ | 0.1784 | 0.1765 | Between $R^2$ | 0.1525 | 0.0882 |
| Within $R^2$ | 0.0306 | 0.0544 | Within $R^2$ | 0.0938 | 0.0550 |

**Note:** The t statistics are given in parenthesis, *, **, *** show 10%、5%、1% statistic significant respectively. The dependent variable is the first difference of warrants price deviations based on GARCH option pricing model. The independent variables are as following: delta_diff_RF is the first difference of diff_RF; delta_diff_RF_issuer is the first difference of diff_RF_issuer; delta_spread_warrant is the first difference of spread_warrant; delta_spread_stock is the first difference of spread_stock; delta_turnover_warrant is the first difference of turnover_warrant; delta_turnover_stock is the first difference of turnover_stock; delta_lambda is the first difference of $\lambda$.

Table 12 Panel Data Analysis Results (At First Deference Level, BS)

| delta_pricing_error_bs | Call | Put | delta_pricing_error_bs | Call | Put |
|---|---|---|---|---|---|
| delta_diff_RF | 0.1006*** | -0.0077 | delta_diff_RF_issue | 0.2672*** | 0.5256*** |
| | (0.0193) | (0.0156) | | (0.0256) | (0.1930) |
| delta_spread_warrant | -5.9612 | 30.2504 | delta_spread_warrant | -12.1498* | 25.3516 |
| | (6.9098) | (21.5756) | | (6.7257) | (21.3559) |
| delta_spread_stock | 10.6854** | -1.5567 | delta_spread_stock | 7.9767* | -1.4615 |
| | (4.7945) | (1.1726) | | (4.6540) | (1.1710) |
| delta_turnover_warrant | 0.0030 | 0.0299*** | delta_turnover_warrant | 0.0025 | 0.0302*** |
| | (0.0028) | (0.0030) | | (0.0027) | (0.0030) |
| delta_turnover_stock | -0.0575 | 0.3421* | delta_turnover_stock | -0.2583 | 0.3551* |
| | (0.4888) | (0.1964) | | (0.4740) | (0.1962) |
| delta_lambda | 11.0297 | -1.1016 | delta_lambda | 38.0389*** | -0.9213 |
| | (7.7480) | (2.6698) | | (7.9640) | (2.6658) |
| constant | 0.0001 | -0.0072*** | constant | 0.0041 | -0.0069*** |
| | (0.0057) | (0.0022) | | (0.0055) | (0.0022) |
| Warrants Effect | Yes | Yes | Warrants Effect | Yes | Yes |
| observation | 1231 | 2165 | observation | 1231 | 2165 |
| Between $R^2$ | 0.1806 | 0.1612 | Between $R^2$ | 0.1431 | 0.4082 |
| Within $R^2$ | 0.0288 | 0.0500 | Within $R^2$ | 0.0887 | 0.0532 |

**Note:** The t statistics are given in parenthesis, *, **, *** show 10%、5%、1% statistic significant respectively. The dependent variable is the first difference of warrants price deviations based on BS option pricing model. The independent variables are as following: delta_diff_RF is the first difference of diff_RF; delta_diff_RF_issuer is the first difference of diff_RF_issuer; delta_spread_warrant is the first difference of spread_warrant; delta_spread_stock is the first difference of spread_stock; delta_turnover_warrant is the first difference of turnover_warrant; delta_turnover_stock is the first difference of turnover_stock; delta_lambda is the first difference of $\lambda$.

Figure 1 Distribution of the Warrants Price Errors Based on GARCH Model

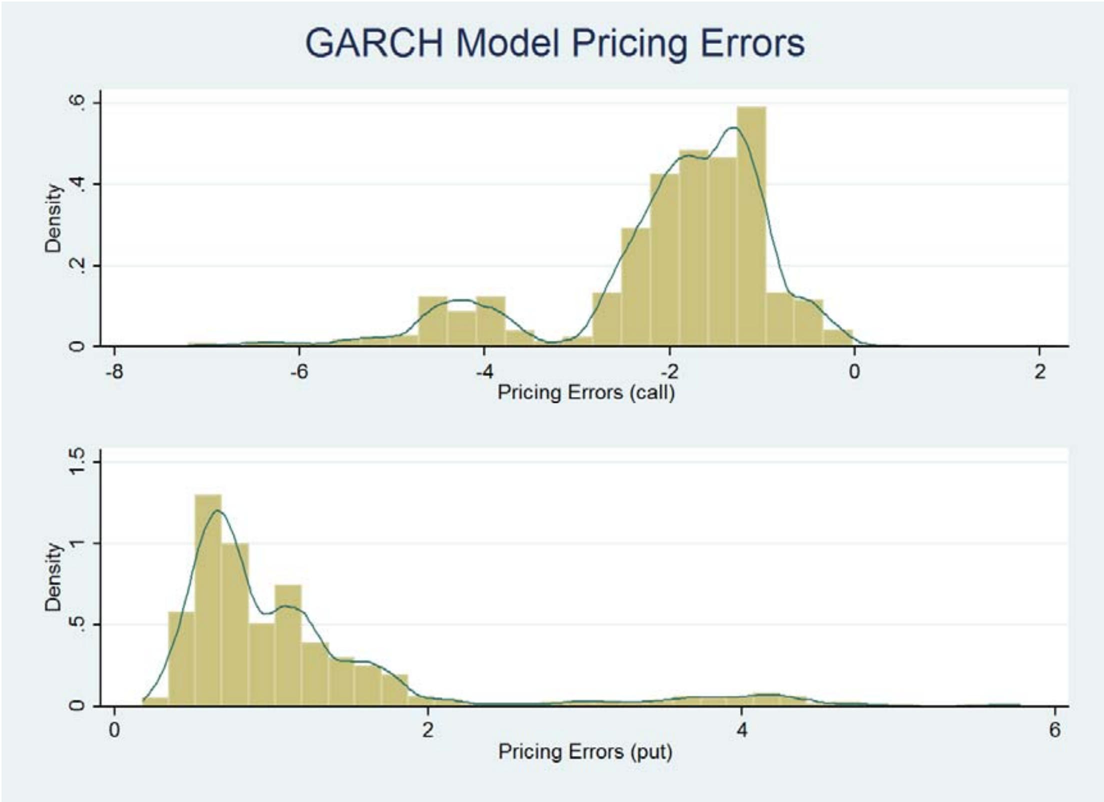


Figure 2 Distribution of the Warrants Price Errors Based on BS Model

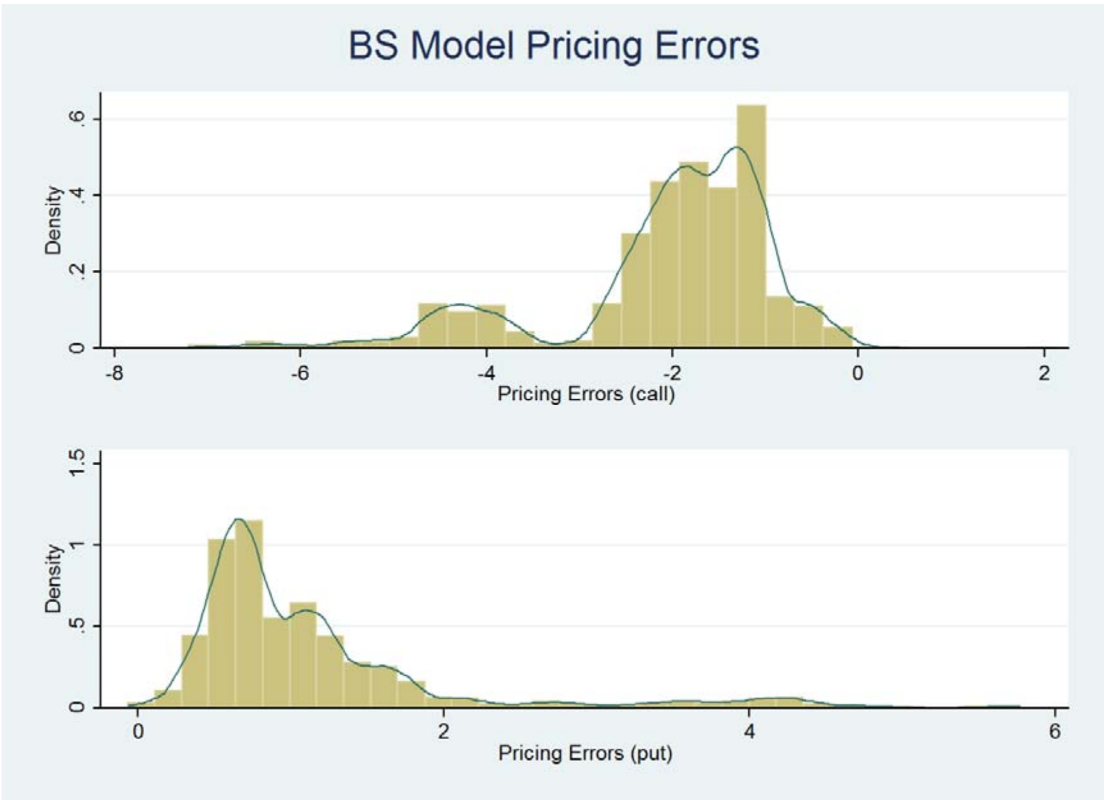

Figure 3 Pricing Errors Smile（Based on GARCH Model）

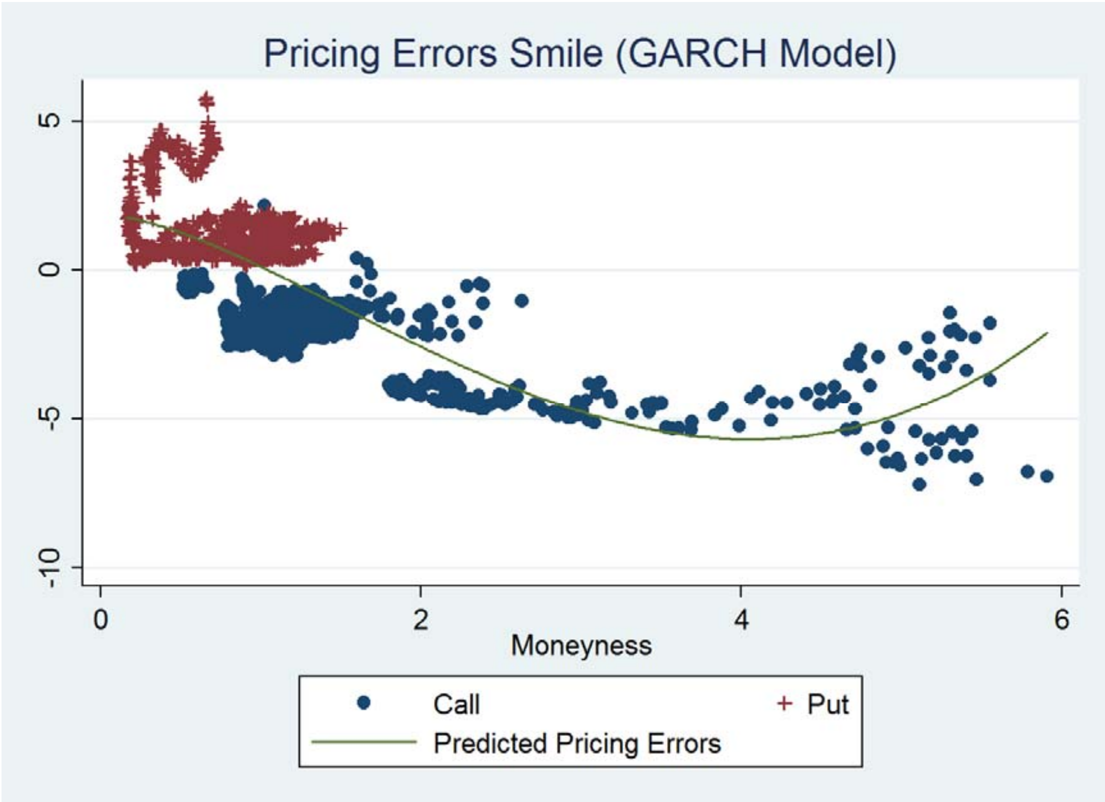


Figure 4 Pricing Errors Smile（Based on BS Model）

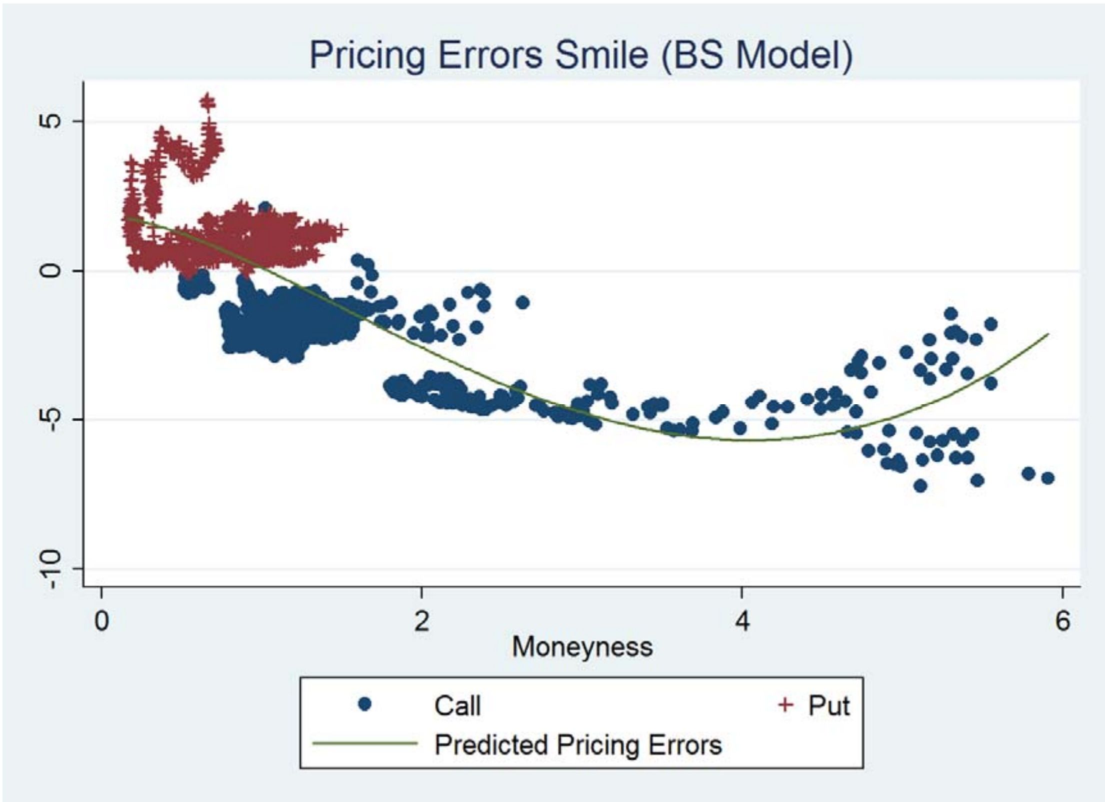

Figure 5 Time Series Variations of Several Variables (Call, Part1)

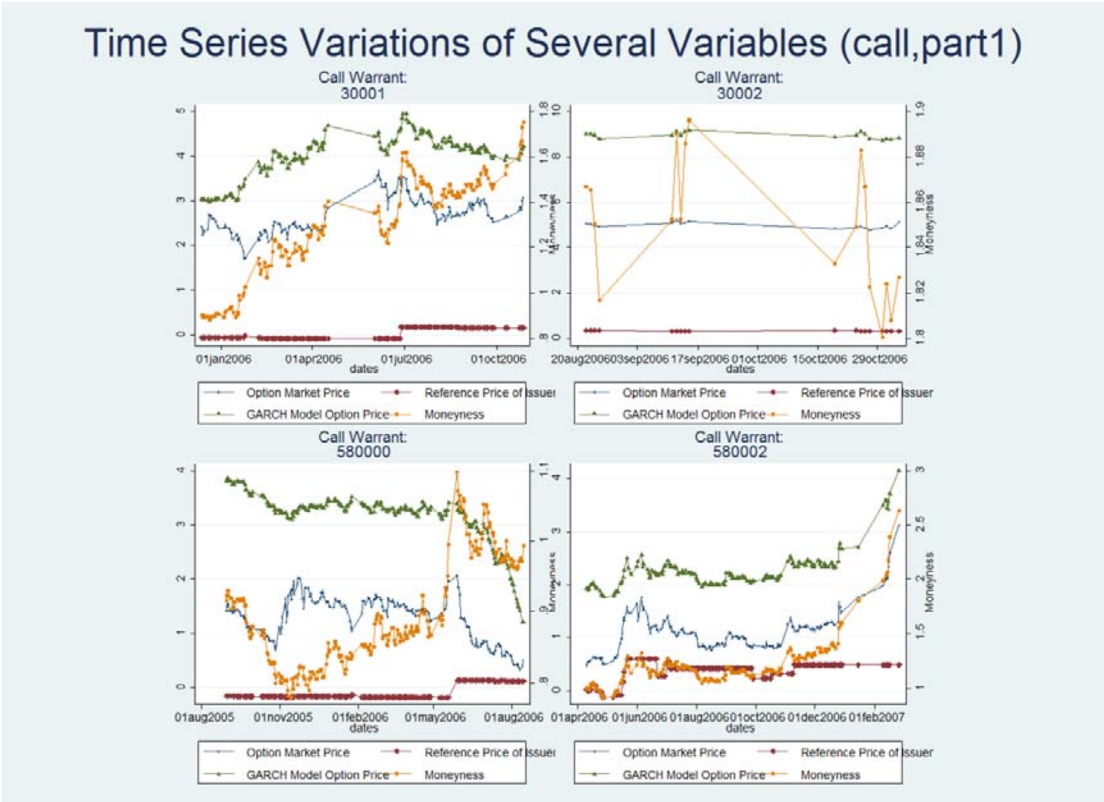


Figure 6 Time Series Variations of Several Variables (Call, Part2)

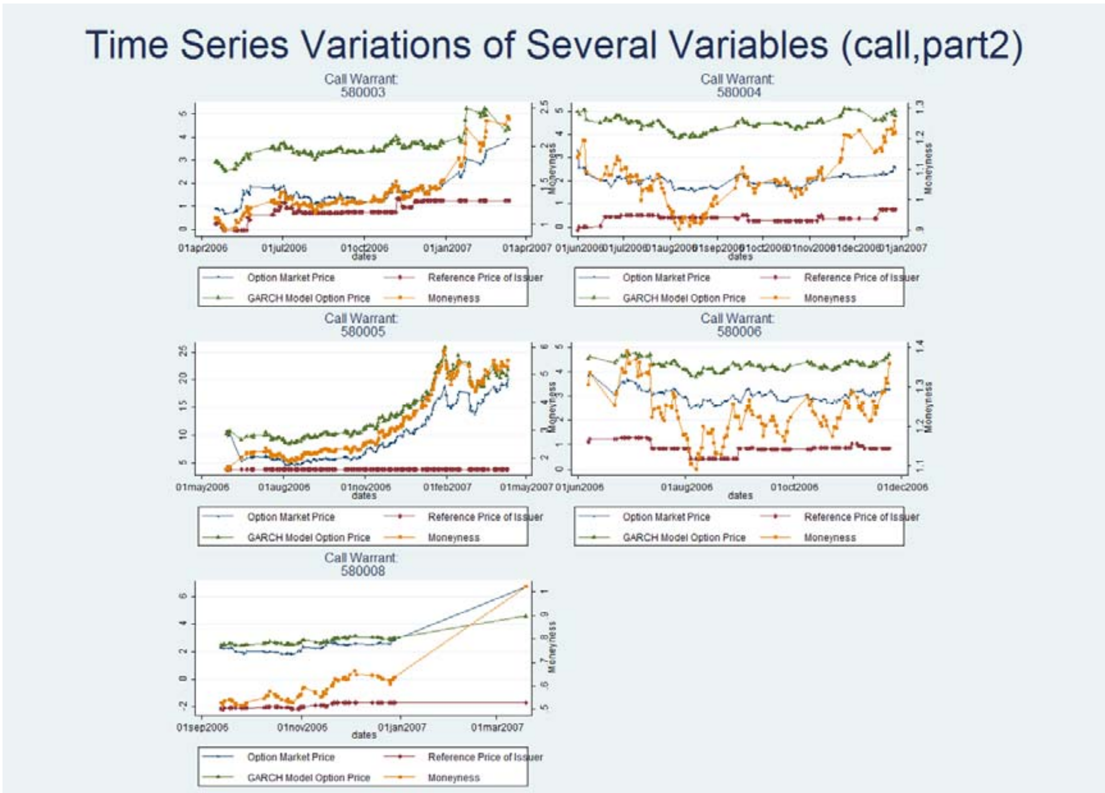

Figure 7 Time Series Variations of Several Variables (Put, Part1)

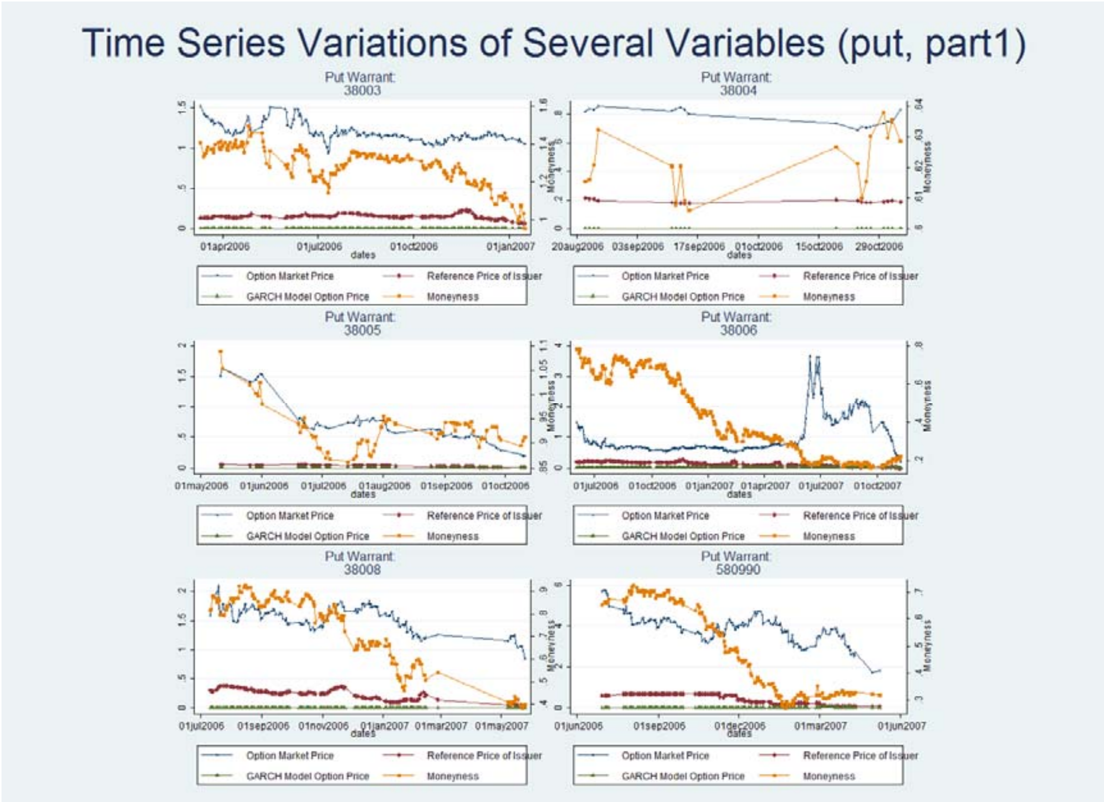


Figure 8 Time Series Variations of Several Variables (Put, Part2)