IS THE BLACK–SCHOLES MODEL GOOD ENOUGH FOR RETAIL INVESTORS IN CHINA?

HAORAN ZHANG[1*]

1. Manhattan College, New York, United States of America

* Corresponding Author: Haoran Zhang, Department of Economics and Finance, Manhattan College, 4513 Manhattan College Parkway, Riverdale, NY 10471, United States ✉ hzhang05@manhattan.edu

Abstract

This study answers a simple question for Chinese investors, especially Chinese retail investors: is the Black–Scholes model good enough for them to make investment decisions? Using the absolute out-of-sample error and the absolute hedging error as measures, I set up empirical tests for the Black–Scholes model's efficiency and find that the volume-weighted mean absolute out-of-sample error is 12.03% of the option premium and that investors must tolerate an absolute error of more than 1% in almost all subsample groups. The volume-weighted mean absolute hedging error is 25.6%, which is far beyond a reasonable level. The significant modelling errors indicate that using the Black–Scholes model solely in the decision-making process may have a negative impact on the investment's performance.

JEL Codes: G13; G15

Keywords: Chinese financial market; options market; Black–Scholes model; retail investors

1. Introduction

The Black–Scholes model has become the classic option pricing model since it was first provided by Black and Scholes (1973) and Merton (1973). The model is based on assumptions, including market and investor assumptions. However, the real world does not work exactly as the model assumes. In the decades after the Black–Scholes model was provided, many studies have improved the model by introducing different underlying processes and relaxing the assumptions (Aït-Sahalia and Lo, 1998; Bakshi et al., 1997; Bates, 1991; Carr and Medan, 1999; Cox and Ross, 1976; Heston and Nandi, 2000; Heston, 1993). With pages of mathematical magic, the studies help financial professionals price options and make investment decisions. The empirical studies on option pricing models in China focus more on the comparison of the models' performances. For example, Huang et al. (2020) compare option pricing models in terms of their in-sample and out-of-sample pricing performance in the Chinese options market. Using the mean-squared error of implied volatility as a measure of the performance, they find that the generalized affine realized volatility model had the best overall performance in the Chinese options market and that all models tested in the study outperformed the Black–Scholes model. However, the advanced models are too complicated for some investors, especially retail investors. Retail investors are among the most important players in the Chinese financial market (Titman et al., 2021). Not many of them are willing to study something complicated, such as stochastic processes, risk-neutral distribution, or the Fast Fourier transform. Still, most investors in the options market have at least heard of the Black–Scholes model, and they can easily find a Black–Scholes calculator online. If the Black–Scholes model is good enough for them to make investment decisions, it may not be necessary to turn to an advanced model. The research question I want to answer in this study is as follows: is the Black–Scholes model good enough for Chinese investors, especially Chinese retail investors? The empirical results indicate that the overall modelling error is high and that most of the subsample groups' modelling errors are intolerable.

The rest of the study is arranged as follows. Section 2 discusses the options market and retail investors in China. Section 3 describes the sample and data. Section 4 presents the empirical results. Section 5 concludes the study.

2. The options market and retail investors in China

In 2015, the first standardized options, 50 Exchange Traded Fund (ETF) options, were officially introduced to the Shanghai Stock Exchange (SSE). Since then, the 50 ETF options had been the only options while trading in the Chinese stock options market until the 300 ETF options were introduced in 2019. As of June 2022, the Chinese stock options market consists of three standardized options: 50 ETF options, 300 ETF options, and 50 index options. In this study, the 50 ETF options will be used as the main sample. These options are European options. The underlying security, SSE 50 ETF, is the most traded ETF in the Chinese equity market. The ETF typically pays dividends yearly in late November or early December. The 50 ETF options contracts are adjusted based on dividend events. Such adjustments eliminate the impact of dividends on option pricing. No tax needs to be paid by investors, and there is only a minor transaction fee, 1.3 Chinese yuan (CNY) per contract, charged by the SSE. Each options contract represents a right to buy or sell 10,000 shares of the Huaxia SSE 50 ETF. The minimum quote price of the option is CNY 0.0001. The daily price change limits on the SSE 50 ETF and the 50 ETF option also impact the market behaviors and efficiency (Chen et al., 2019; Deb et al., 2010; Lien et al., 2019; Reiffen et al., 2006;). If the price of the underlying ETF changes by more than 10%, the ETF trading will be suspended for the trading day. The trading of an options contract will be suspended if the premium hits the daily limit.[1] The underlying ETF can be short-sold. During the 2015 financial crisis, an implicit short-selling restriction was set, so short-selling was effectively banned. However, the impact of short-selling on the derivatives market vanished after 2016 (Zhang, 2022). In summary, using the Black–Scholes model to price the 50 ETF options has pros and cons, and the model has the potential to work well for the options.

One feature that makes the Chinese securities markets so special is the significant role of retail investors in the markets. Retail investors are big fans of the securities markets in China and view them as the "road to financial freedom." On the other hand, they may not have the ability to process complicated market information. About one-third of retail investors in China do not have high school degrees (Jiang et al., 2020; Titman et al., 2021). A retail investor can obtain the financial options' trading permission if the investor (1) has an A-share stock market investment account, (2) has traded with this account for more than six months, (3) maintains a mean account value of CNY 500,000 over a 20-trading-day period, and (4) passes a qualification test. As of the end of 2021, the total number of accounts that have options trading permissions was 542,400. Most of the accounts were retail investors' accounts. In 2021, in terms of trading volume, retail investors contributed 41.22% of the call options and 37.11% of the put options (Shanghai Stock Exchange, 2021). This group of investors is a significant force in the Chinese options market. As discussed in the first section, retail investors may not be interested in the

[1] The maximum daily call premium increase is max {0.5%×C_{t-1}, min [(2×$C_{t-1} - K$), 10%×C_{t-1}]}. The maximum daily put premium increase is max {0.5%×K, min [(2×$K - P_{t-1}$), 10%×P_{t-1}]}. C_{t-1} and P_{t-1} are the previous close option premiums. The maximum daily option premium decrease is 10% of the previous close option premium.

complicated option pricing models or may not have the time or ability to learn the models. Compared to retail investors, institutional investors have more flexibilities on the option pricing models. The Black–Scholes model may still be used by institutional investors, but they are expected to know the model well and understand its pros and cons. Furthermore, when an institutional investor needs to use the advanced models, it has access to the experts in the models. On the other hand, investors in developed markets may also use the Black–Scholes model to guide their investment decisions. However, a significant part of options in these markets consists of American options, for which the Black–Scholes model is not suitable. Even Bloomberg Terminals provide Black–Scholes estimates for American options. Investors are expected to know this and adjust their decision-making process. However, all financial options traded in China are European options. The market setups may give Chinese retail investors confidence that the Black–Scholes model can be used to price the options in China. When Chinese retail investors need a model to help them make investment decisions, they may simply find the inputs from the Bloomberg system or other data sources and use a Black–Scholes calculator online to price the options. In this case, can they get high-quality information from the Black–Scholes model? I answer this question in Section 4.

3. Data and Samples

The sample in this study includes all 50 ETF options contracts in the Chinese market. All observations without any daily trading volume are excluded. Option data comes from Bloomberg. The Bloomberg system returns abnormal data on the maturities of some contracts, so all observations on the maturities are excluded.

The Shanghai Interbank Offer Rate (SHIBOR) serves as the risk-free rate. SHIBOR benchmarks are provided on the SHIBOR website (www.shibor.org).

The sample period spans from October 2017 to September 2019. The start point is set to October 2017 to minimize the impact of short-selling and trading constraints set during the 2015 Chinese financial crisis (Hilliard and Zhang, 2019; Miao et al., 2017). The impact is minor after 2016 (Zhang, 2022). Lin et al. (2021) find that the COVID-19 pandemic has a significant impact on the option pricing in the Chinese options market. Thus, to avoid the pandemic period, the endpoint of the sample period is September 2019.

4. Methodology and empirical results

In this study, I followed Bakshi et al. (1997) to estimate the out-of-sample error and use the absolute out-of-sample error as a measure of the Black–Scholes model's efficiency. Implied volatility is calculated for each contract on each day, and this implied volatility is then used as an input to calculate the Black–Scholes implied premium for the same contract on the following business day. The out-of-sample errors and absolute out-of-sample errors are estimated using Equations (1) and (2):

$$Error_{i,t} = \frac{Premium_{i,t} - BS(\sigma_{i,t-1}; \Omega_{i,t})}{Premium_{i,t}}, \quad (1)$$

$$AbsError_{i,t} = \left|Error_{i,t}\right|, \tag{2}$$

where $Premium_{i,t}$ is the option premium of contract *i* on day *t*. $BS(\sigma_{i,t-1})$ is the Black–Scholes implied option premium using the previous trading day's volatility, $\sigma_{i,t-1}$, as an input. All other inputs are related variables of contract *i* on day *t* ($\Omega_{i,t}$). $BS(\cdot)$ is defined by Equations (3) and (4):

$$C_{i,t} = N(d_1)S_{i,t} - N(d_2)K_i e^{-r_{i,t}(T_i-t)}, \tag{3}$$

$$P_{i,t} = N(-d_2)K_i e^{-r_{it}(T_i-t)} - N(-d_1)S_{i,t}, \tag{4}$$

Where $d_1 = \frac{\ln\left(\frac{S_{i,t}}{K_i}\right)+(r_{i,t}+\frac{\sigma_{i,t}^2}{2})(T_i-t)}{\sigma_{i,t}\sqrt{T_i-t}}$ and $d_2 = d_1 - \sigma_{i,t}\sqrt{T_i - t}$. $S_{i,t}$ and $r_{i,t}$ are the underlying prices and the interpolated interest rate of contract *I* on day *t*, respectively. K_i and T_i are the exercise price and the maturity of contract *i*, respectively. $\sigma_{i,t}$ is the volatility of contract *i* on day *t*.

Table 1 reports the volume-weighted mean errors and absolute errors of the whole sample and subsamples. As shown in Panel A, the mean absolute errors are 12.03% of the actual option premium for the whole sample, 12.12% for the call options, and 11.92% for the put options. The absolute errors are lower for contracts with longer term to maturity. The overall volume-weighted mean absolute error is 12.52% for short-term contracts, 8.70% for mid-term contracts, and 6.78% for long-term contracts.

The absolute errors are the lowest for deep-in-the-money contracts (1.37% for call options and 1.26% for put options) and the highest for deep-out-of-the-money contracts (29.67% for call options and 27.10% for put options). Put options have lower absolute errors in almost all subgroups. All volume-weighted means in Panel A are statistically significant at the 1% level. If 1% is assumed to be the threshold for the unacceptable error level, the Black–Scholes model is not acceptable for 59 out of 60 sample groups in Panel A. If the threshold is set to 5%, which is a highly unrealistic tolerance level for financial market trading, the model is not acceptable for 40 out of 60 sample groups. The high level of absolute errors will significantly impact the investors' decision-making process.

Panel B shows volume-weighted mean errors. Almost all mean errors (55 out of 60 in the panel) are negative, implying that using the method will systemically overestimate the premiums of options contracts. The overall errors are −1.73% for the full sample, −1.06% for the call options, and −2.49% for the put options. The deep-out-of-the-money options have the lowest value (−7.52% for calls and −11.4% for puts), while the in-the-money options have relatively low deviations from zero (−0.60% for calls and −0.44% for puts). Most of the mean errors in Panel B (46 out of 60) are statistically significant at the 1% level.

Table 1: Out-of-sample errors

	All (Call and Put)				Call				Put			
Panel A: Absolute errors												
	All	Short (<45)	Mid (45–120)	Long (>120)	All	Short (<45)	Mid (45–120)	Long (>120)	All	Short (<45)	Mid (45–120)	Long (>120)
All	0.1203***	0.1252***	0.0870***	0.0679***	0.1212***	0.1260***	0.0887***	0.0622***	0.1192***	0.1242***	0.0851***	0.0732***
<0.9	0.2580***	0.3278***	0.1701***	0.0921***	0.2967***	0.3823***	0.1878***	0.1043***	0.0127***	0.0087***	0.0171***	0.0255***
0.9–0.97	0.1614***	0.1744***	0.0857***	0.0552***	0.2012***	0.2184***	0.1002***	0.0614***	0.0251***	0.0238***	0.0319***	0.0375***
0.97–1.03	0.0825***	0.0847***	0.0504***	0.0487***	0.0839***	0.0863***	0.0495***	0.0480***	0.0807***	0.0828***	0.0515***	0.0496***
1.03–1.1	0.1469***	0.1578***	0.0789***	0.0608***	0.0239***	0.0236***	0.0224***	0.0332***	0.1884***	0.2035***	0.0962***	0.0705***
1.1<	0.2432***	0.3246***	0.1332***	0.1013***	0.0137***	0.0133***	0.0103***	0.0213***	0.2710***	0.3655***	0.1458***	0.1102***
Panel B: Errors												
	All	Short (<45)	Mid (45–120)	Long (>120)	All	Short (<45)	Mid (45–120)	Long (>120)	All	Short (<45)	Mid (45–120)	Long (>120)
All	−0.0173***	−0.0181***	−0.0110***	−0.0112***	−0.0106***	−0.0107***	−0.0115***	−0.0046***	−0.0249***	−0.0266***	−0.010**	−0.0175***
<0.9	−0.0656***	−0.0914***	−0.0357***	0.0015	−0.0752***	−0.1065***	−0.0391***	0.0034	−0.0044***	−0.0030***	−0.0061***	−0.0086***
0.9–0.97	−0.0228***	−0.0248***	−0.0106***	−0.0069***	−0.0280***	−0.0309***	−0.0108***	−0.0057***	−0.0047***	−0.0039***	−0.0099***	−0.0102***
0.97–1.03	−0.0006	−0.0003	−0.0052***	−0.0089***	0.0021	0.0024	−0.0019	−0.0075***	−0.0039	−0.0035*	−0.0092***	−0.0106***
1.03–1.1	−0.0380***	−0.0429***	−0.0014	−0.0134***	−0.0029***	−0.0030***	0.0005	−0.0084***	−0.0498***	−0.0565***	−0.0020	−0.0152***
1.1<	−0.1026***	−0.1557***	−0.0217***	−0.0260***	−0.0060***	−0.0076***	−0.0002	−0.0075***	−0.1143***	−0.1752***	−0.0239***	−0.0280***

Note: This table shows the volume-weighted mean out-of-sample errors and absolute out-of-sample errors. The errors are estimated by Equations (1)–(4). ***, **, and * indicate the significant levels of 1%, 5%, and 10%, respectively. The sample is sorted into subsample groups by moneyness, term to maturity, and option type. Moneyness is defined as the underlying price divided by the strike price. The four moneyness thresholds are 0.9, 0.97, 1.03, and 1.1. The two time-to-maturity thresholds are 45 and 120 days.

The method above is still too complicated for retail investors in China. Again, most retail investors may not be interested in estimating the inputs, such as the implied volatility and interpolated interest rate, of the Black–Scholes model. A more realistic case is that retail investors directly use the implied volatilities shown in the Bloomberg system to estimate the Black–Scholes implied premium. To estimate the out-of-sample error in this case, Equation (1) is replaced by Equation (5):

$$Error_{i,t} = \frac{Premium_{i,t} - BS\left(\hat{\sigma}_{i,t-1}; \Omega_{i,t}\right)}{Premium_{i,t}}, \tag{5}$$

where $\hat{\sigma}_{i,t-1}$ is the "observed" implied volatility in the Bloomberg system for contract *i* on day *t*−1. All other variables are the same as in the previous part.

As shown in Panel A of Table 2, the volume-weighted mean absolute errors are 15.47% for the whole sample, 15.71% for call options, and 15.24% for put options. The mean absolute error of each sample/subsample group is higher than that of the same sample/subsample group reported in Panel A of Table 1. This means that in this more realistic case, investors, especially retail investors, must tolerate more model errors. In-the-money contracts still have higher absolute errors than out-of-the-money contracts, while the mid-term contracts have the lowest mean absolute errors. In Panel B, the volume-weighted mean errors are −3.17% for the whole sample, −0.74% for call options, and −5.97% for put options. More than half of the sample/subsample groups produce significant negative errors.

Table 2: Out-of-sample errors using implied volatilities from Bloomberg

	All (Call and Put)				Call				Put			
Panel A: Absolute errors												
	All	Short (<45)	Mid (45–120)	Long (>120)	All	Short (<45)	Mid (45–120)	Long (>120)	All	Short (<45)	Mid (45–120)	Long (>120)
All	0.1547***	0.1549***	0.1441***	0.1759***	0.1571***	0.1570***	0.1498***	0.1779***	0.1519***	0.1524***	0.1375***	0.1738***
<0.9	0.3026***	0.3644***	0.2000***	0.2035***	0.3424***	0.4189***	0.2186***	0.2272***	0.0579***	0.0595***	0.0409***	0.0746***
0.9–0.97	0.1871***	0.1957***	0.1225***	0.1524***	0.2268***	0.2389***	0.1410***	0.1694***	0.0535***	0.0512***	0.0539***	0.1035***
0.97–1.03	0.1234***	0.1229***	0.1215***	0.1644***	0.1288***	0.1272***	0.1426***	0.1821***	0.1167***	0.1175***	0.0945***	0.1424***
1.03–1.1	0.1705***	0.1725***	0.1491***	0.1732***	0.0732***	0.0664***	0.1167***	0.1505***	0.2163***	0.2237***	0.1613***	0.1836***
1.1<	0.2617***	0.3045***	0.1896***	0.2006***	0.0592***	0.0527***	0.0569***	0.0975***	0.3093***	0.3739***	0.2105***	0.2219***
Panel B: Errors												
	All	Short (<45)	Mid (45–120)	Long (>120)	All	Short (<45)	Mid (45–120)	Long (>120)	All	Short (<45)	Mid (45–120)	Long (>120)
All	−0.0313***	−0.0354***	0.003	0.0013	−0.0074***	−0.0168***	0.0528***	0.1239***	−0.0597***	−0.0579***	−0.0539***	−0.1214***
<0.9	−0.0308***	−0.0762***	0.0096**	0.1158***	−0.0273***	−0.0798***	0.0149**	0.1482***	−0.0526***	−0.0559***	−0.0356***	−0.0606***
0.9–0.97	−0.0215***	−0.0291***	0.0165***	0.0635***	−0.0199***	−0.0304***	0.0275***	0.1097***	−0.0266***	−0.0250***	−0.0243***	−0.0691***
0.97–1.03	−0.0206***	−0.0239***	0.0282***	0.0288***	−0.0045	−0.0114***	0.0848***	0.1370***	−0.0405***	−0.0394***	−0.0444***	−0.1056***
1.03–1.1	−0.0522***	−0.0556***	−0.0174**	−0.0558***	0.0142***	0.0039	0.0870***	0.1154***	−0.0836***	−0.0843***	−0.0569***	−0.1336***
1.1<	−0.1266***	−0.1563***	−0.0620***	−0.1084***	0.0006	−0.0208***	0.0353***	0.0702***	−0.1565***	−0.1936***	−0.0774***	−0.1453***

Note: This table reports the volume-weighted mean out-of-sample errors and absolute out-of-sample errors. The errors are estimated by Equations (1), (5), (3), and (4). ***, **, and * indicate the significant levels of 1%, 5%, and 10%, respectively. The sample is sorted into subsample groups by moneyness, term to maturity, and option type. Moneyness is defined as the underlying price divided by the strike price. The four moneyness thresholds are 0.9, 0.97, 1.03, and 1.1. The two time-to-maturity thresholds are 45 and 120 days.

To further evaluate the model efficiency of the Black–Scholes model, I use the hedging error of the delta-neutral strategy as another measure of modelling efficiency. The delta-neutral strategy is used widely to reduce option investment risk. A hedging portfolio with a delta of zero is established each day for each contract, and then the hedging error is evaluated in the next day. Hedging errors are estimated with Equation (6).

$$HedgingError_{i,t} = \left| \frac{(Premium_{i,t} - Premium_{i,t-1}) - \widehat{\Delta}_{i,t-1}(Price_{i,t} - Price_{i,t-1})}{Premium_{i,t}} \right|, \quad (6)$$

where $\widehat{\Delta}_{i,t-1}$ is $N(d_1)$ for call options or $N(d_1) - 1$ for put options, estimated with the inputs in day t−1[2].

As shown in Table 3, the overall hedging error is 25.6%, indicating that to hedge an option position of CNY 100, an investor must bear an average hedging error of CNY 25.6. The overall hedging errors for call options and for put options are 24.15% and 27.15%, respectively. The hedging errors for short-term contracts are much higher than those for mid-term or long-term contracts. The hedging errors are also overall higher for in-the-money contracts, but the groups with the highest hedging errors are not the deep-in-the-money group. The 0.9–0.97 moneyness group for call options and the 1.03–1.1 moneyness group for put options have the highest hedging errors. All errors are significant at 1%.

[2] The volatility in day t−1, $\sigma_{i,t-1}$, is estimated by the implied volatility in the previous day, t−2, of the same contract. Observations with no volume in day t, day t−1, and/or day t−2 are excluded.

Table 3: Hedging errors

	All (Call and Put)				Call				Put			
	All	Short (<45)	Mid (45–120)	Long (>120)	All	Short (<45)	Mid (45–120)	Long (>120)	All	Short (<45)	Mid (45–120)	Long (>120)
All	0.2560***	0.2852***	0.0901***	0.0648***	0.2415***	0.2676***	0.0874***	0.0603***	0.2715***	0.3042***	0.0929***	0.0691***
<0.9	0.2555***	0.3674***	0.1549***	0.0890***	0.2952***	0.4324***	0.1714***	0.1018***	0.0133***	0.0087***	0.0155***	0.0242***
0.9–0.97	0.3213***	0.3727***	0.0852***	0.0554***	0.4067***	0.4732***	0.1003***	0.0615***	0.0326***	0.0324***	0.0304***	0.0380***
0.97–1.03	0.1987***	0.2116***	0.0514***	0.0465***	0.2012***	0.2144***	0.0508***	0.0456***	0.1958***	0.2082***	0.0520***	0.0476***
1.03–1.1	0.3623***	0.4183***	0.0874***	0.0603***	0.0339***	0.0352***	0.0244***	0.0307***	0.4719***	0.5478***	0.1069 ***	0.0699***
1.1<	0.2768***	0.4003***	0.1345***	0.0954***	0.0114***	0.0091***	0.0115***	0.0193***	0.3087***	0.4468***	0.1493***	0.1049***

Note: This table reports the volume-weighted mean delta-neutral hedging errors. The errors are estimated by Equation (6). ***, **, and * indicate the significant levels of 1%, 5%, and 10%, respectively. The sample is sorted into subsample groups by moneyness, term to maturity, and option type. Moneyness is defined as the underlying price divided by the strike price. The four moneyness thresholds are 0.9, 0.97, 1.03, and 1.1. The two time-to-maturity thresholds are 45 and 120 days.

5. Conclusion

In this study, I use the 50 ETF options as samples to answer a simple question: is the Black–Scholes model good enough for investors in China? I find that the investors must tolerate a 12.03% absolute out-of-sample error if they use the Black–Scholes model solely to make investment decisions. If the investors use the implied volatility from the Bloomberg system directly, the absolute out-of-sample error increases to 15.47%. The model performs the best for deep-in-the-money contracts and the worst for deep-out-of-the-money options. The absolute errors of most of the sample/subsample groups are much higher than the tolerable level (1% or 5%). Furthermore, the absolute hedging error is 25.6%, which is too high for a hedging strategy. As such, the Black–Scholes model is not a good enough model to help investors make decisions in the Chinese options market.

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