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Understanding the complex dynamics of financial markets through microsimulation

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Chapter 6

Effects of Heterogeneous Speculative Strategies on the Volatility Smile

We have studied the market mechanism underlying the volatility smile phenomenon through a microsimulation (MS) model of options markets, described in Chapter 5. The model is able to reproduce the volatility smile and its dynamic properties in a simple and robust manner, and can explain the related stylized facts observed in real markets. It mainly adopts one type of speculative strategy, i.e. simple directional (SD) speculation, supported by the finding of a recent empirical study reported in Lakonishok et al. (2007).

However, it is still not clear how other commonly-used speculative strategies, which can be generally classified into directional strategies and volatility strategies, influence the smile. We hence investigate the effects of these strategies on the shape the IV curve[1]. Since the strategies coexist with the SD strategy in real markets, this study is indispensable for the comprehensive understanding of the volatility smile phenomenon.

We first describe the main heterogeneous speculative strategies included in our model in Section 6.1. Through simulations we study the effects of these strategies on the IV curve. The simulation results and our conclusions are discussed in

[1] This chapter is based on Qiu et al. (2010c)

Sections 6.2, 6.3 and 6.4, respectively.

6.1 Modeling heterogeneous speculators

The trading behavior of different types of speculator is based on their views on certain determinant factors that control the expected profits from employing the specific trading strategies. Rudimentary speculative strategies can be classified into two types: Directional and volatility. Directional strategies profit from either rising or falling price movements of the underlying, while volatility speculations rely on absolute price movements regardless of the direction.

Speculators are generally heterogeneous with respect to their judgments about the values of the determinant factors. The judgments are influenced by news and change overtime. However, since we are investigating the general effects of the strategies on the shape of smile, we assume that they are constant for simplicity. Directional spread speculators have different expectations regarding the future price of the underlying, denoted as $S^i_{SP\_D}$. Volatility spread speculators expect different levels of the fluctuations in the future price, represented by $W^i_{SP\_V}$, which is the absolute difference between two prices symmetric to the spot price, denoted respectively as $S^i_{SP\_V,S}$ (S for 'small') and $S^i_{SP\_V,L}$ (L for 'large').

Directional spread (DSPR) traders are the most typical directional speculators, apart from the simple directional (SD) traders. A typical volatility trading strategy is the so-call butterfly spread (BSPR) speculation. Detailed discussions about the payoffs of these strategies can be found in, among many others, Natenberg (1994) and Hull (2003). The corresponding profit diagrams are shown in Figure 6.1. Briefly, these two strategies involve combinations of a few options and the profit of each portfolio is the sum of the profits of the constituent options. In the next section, we will discuss these strategies in more detail.

6.1.1 Directional spread speculation

A typical DSPR strategy involves a position in two call/put options. A bull spread is created by buying a call/put option with a certain strike K^{n_1} and selling another call/put option with a higher strike K^{n_2}. It restrains the investor's upside potential. In return, the investor limits the downside risk and finances the purchasing through the selling. Bull spreads benefit from an increase in the price of the underlying. By contrast, a bear spread is constructed by reversing the positions, i.e. buying a call/put option with a certain strike and selling another call/put option with a lower strike. It also limits the investor's upside potential as well as downside risk, and receives premiums through selling options. Bear spread benefits from an price decrease of the underlying.

Based on their assessments of the price of the underlying, the DSPR speculators can estimate the profits from trading the individual options, denoted as $E^{i,n,\phi,t}_{SP\_D}$.

$$E^{i,n,\phi,t+1}_{SP\_D} = max(\phi(S^{i,t}_{SP\_D} - K^n), 0) - V^{n,\phi,t}, \tag{6.1}$$

where $max(\phi(S^{i,t}_{SP\_D} - K^n), 0)$ is the payoff as estimated by the trader that can be gained from buying the option; $V^{n,\phi,t}$, which is the market price of the option, represents the cost for establishing this long position. The speculator's expected profit from selling the option is $-E^{i,n,\phi,t+1}_{SP\_D}$.

We assume that the transaction quantities of each DSPR trader are determined by the trader's activity level and expected profit of the portfolio, namely

$$\begin{pmatrix} Q^{i,n_1,\phi,t+1}_{SP\_DSPR} \\ \\ Q^{i,n_2,\phi,t+1}_{SP\_DSPR} \end{pmatrix} = \begin{pmatrix} 1 \\ \\ -1 \end{pmatrix} \lambda_{SP\_DSPR} \, (E^{i,n_1,\phi,t+1}_{SP\_D} - E^{i,n_2,\phi,t+1}_{SP\_D}), \tag{6.2}$$

in which λ_{SP_DSPR} is a positive parameter which reflects the activity level of the DSPR speculators.

6.1.2 Butterfly spread speculation

A BSPR portfolio is created by buying a call/put option with a relatively low strike K^{n_1}, buying a call/put option with a relatively high strike K^{n_3}, and selling two call/put options with a medium strike K^{n_2} equally distant from the other two strikes. Generally the middle strike is close to the current price of the underlying. A butterfly spread leads to a profit/loss if the underlying stays close to/(move significantly to either direction from) its current price. This spread can be sold

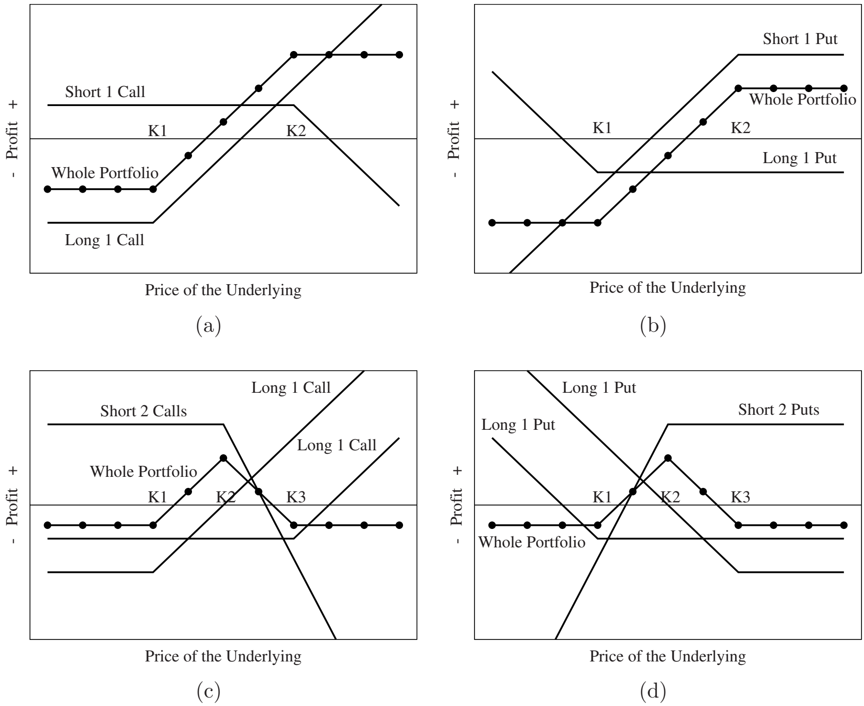


Figure 6.1: Profit diagrams of directional spread (DSPR) and butterfly spread (BSPR) speculative strategies. (a) A DSPR portfolio composed of call options. (b) A DSPR portfolio composed of put options. (c) A BSPR portfolio composed of call options. (d) A BSPR portfolio composed of put options.

by reversing the positions. BSPR speculations limit the investors' profits as well as risk.

Based on their assessments of the price of the underlying, the BSPR speculators can estimate the profits from trading the individual options, denoted as $E^{i,n,\phi,t}_{SP\_V}$. It is the average of the profit estimated according to the trader's lower expected price ($S^{i,t}_{SP\_V,S}$) and that according to the higher expected price ($S^{i,t}_{SP\_V,L}$),

$$\begin{aligned} E^{i,n,\phi,t+1}_{SP\_V} &= \frac{1}{2}[(max(\phi(S^{i,t}_{SP\_V,S} - K^n), 0) - V^{n,\phi,t} \\ &\quad + max(\phi(S^{i,t}_{SP\_V,L} - K^n), 0) - V^{n,\phi,t})], \end{aligned} \tag{6.3}$$

where $max(\phi(S^{i,t}_{SP\_V,(\cdot)} - K^n), 0)$ and $V^{n,\phi,t}$ are respectively the payoff as estimated by the volatility trader and the cost of the long position. The trader's expected profit from selling the option is $-E^{i,n,\phi,t+1}_{SP\_V}$.

We assume that the transaction quantities of each BSPR trader for the options are determined by the trader's activity level and expected profit of the portfolio, namely

$$\begin{pmatrix} Q^{i,n_1,\phi,t+1}_{SP\_BSPR} \\ Q^{i,n_2,\phi,t+1}_{SP\_BSPR} \\ Q^{i,n_3,\phi,t+1}_{SP\_BSPR} \end{pmatrix} = \begin{pmatrix} 1 \\ -2 \\ 1 \end{pmatrix} \lambda_{SP\_BSPR} (E^{i,n_1,\phi,t+1}_{SP\_V} - 2E^{i,n_2,\phi,t+1}_{SP\_V} + E^{i,n_3,\phi,t+1}_{SP\_V}), \tag{6.4}$$

in which λ_{SP_BSPR} is a positive parameter indicating the activity level of the BSPR speculators.

We further assume that the speculators are equally active in applying all possible strategies. However, the various strategies differ in the number of potential portfolios in which traders can invest. In addition, different from SD speculators' trading activity which is strike dependent, DSPR and BSPR speculators' trading activity is identical across strikes. We take these differences into consideration in choosing values for λ_{SP_DSPR} and λ_{SP_BSPR}. The detailed explanations, functional forms, and values adopted for these activity parameters are described in Appendix C.

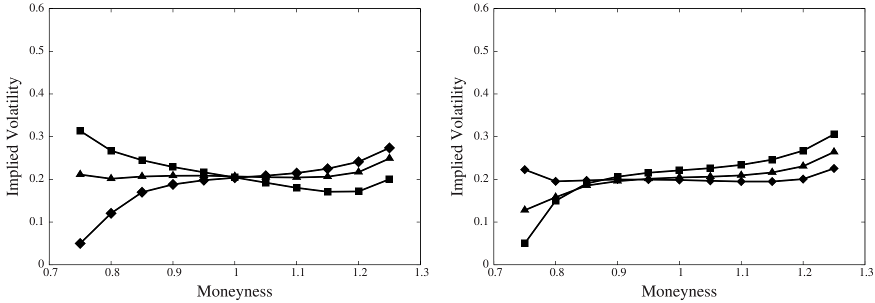
6.2 Effects on the volatility smile

Here we study the influences of the DSPR and BSPR speculators on the IV curve produced by the SD traders, by examining the shape of the IV curve when they separately trade together with the SD traders. Firstly, we adopt different fractions of the various types of speculator. Secondly, we fix the fraction of each type of traders and adopt different values for the parameters of the distributional properties of the relevant determinant factor. In explaining the mechanisms underlying the effects, we refer to the profit diagrams of the speculative strategies displayed in Figure 6.1. If the profit corresponding to an speculator's expected price is positive/negative according to the diagram, the trader will buy/sell the portfolio.

6.2.1 Directional spread speculators

We again consider the situation that the mean of the expected prices of the directional speculators is smaller than the market price of the underlying. In this case, as shown in Figure 6.1(a) and Figure 6.1(b), more traders will expect negative profits from purchasing the DSPR call and put portfolios, in comparison with the situation that the mean is equal to the market price which gives rise to a symmetric IV curve. Therefore, more traders will sell/buy call and put options with lower/higher strikes, leading to a upward sloping IV curve, and vice versa.

In Chapter 5, we have shown that in the same situation, the SD speculators instead produce a downward sloping IV curve. When trading together with SD speculators, the DSPR speculators hence tend to reverse the skewness generated by the former. The more DSPR traders are in the market, the more the skewness is reversed, as shown in Figure 6.2(a). In addition, if the difference between the directional speculators' expected prices and the spot price of the underlying is increased, the slope of the IV curve will increase, as is displayed in Figure 6.2(b).

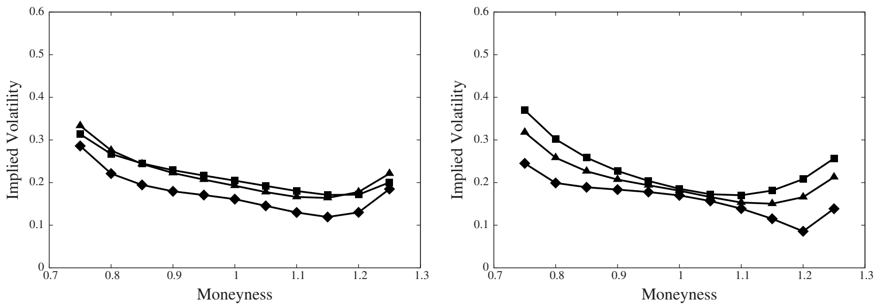


(a) (b)

Figure 6.2: IV curves if the directional spread (DSPR) speculators trade together with the simple directional (SD) speculators. The fraction of arbitrageurs is 30%, the mean of the SD speculators' expected prices is 19, and the current price of the underlying asset is 20. (a) The fractions of the DSPR speculators are 0% (the ■ line), 20% (▲ line), and 50% (the ♦ line) respectively. Here, the mean of the DSPR speculators' expected prices is 19. (b) The mean of the DSPR speculators' expected prices are 18 (the ■ line), 19 (the ▲ line), and 20 (the ♦ line) respectively. Here, the fraction of the SD speculators and that of the DSPR speculators are both 35%.

6.2.2 Butterfly spread speculators

Firstly, as shown in Figure 6.3(a), BSPR traders can change the level of the smile. Secondly, when the average price fluctuation level of the BSPR speculators becomes higher, as shown in Figure 6.1(c) and Figure 6.1(d), more traders will expect negative profits from purchasing the BSPR call and put portfolios, and vice versa. Consequently more ITM and OTM call and put options will be sold and in the meantime more ATM call and put options will be bought. This leads to a decrease of the prices of the ITM and OTM options and an increase of the price of the ATM option. Therefore the IV curve becomes less convex, as shown in Figure 6.3(b).

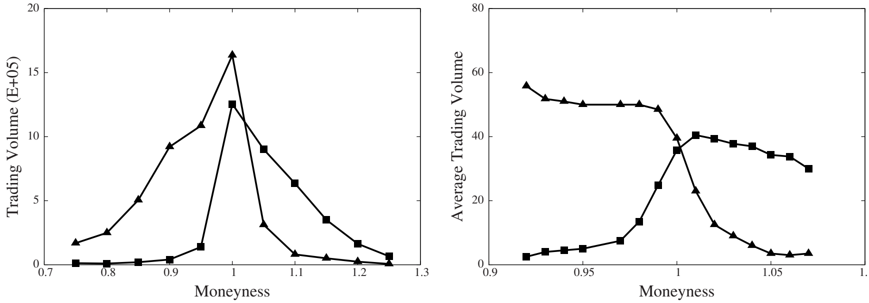


(a) (b)

Figure 6.3: IV curves if the butterfly spread strategies (BSPR) speculators trade together with the simple directional (SD) speculators. The fraction of arbitrageurs is 30%, the mean of the SD speculators' expected prices is 19, and the current price of the underlying asset is 20. (a) The fractions of the BSPR speculators are 0% (the ■ line), 20% (▲ line), and 50% (the ♦ line) respectively. Here, the mean of the BSPR speculators' expected variance are 4. (b) The mean of the BSPR speculators' expected variance are 3 (the ■ line), 4 (the ▲ line), and 5 (the ♦ line) respectively. Here,the fraction of the BSPR speculators is 35%

6.3 Analysis of the trading volumes

Although DSPR and BSPR speculators can change the IV curve to a certain extent, they are not the dominant speculators in real markets. This can be justified by comparing the trading volumes produced by the different types of speculator (together with arbitrageurs) in our model with those recorded in real markets. Two examples of empirical volume distributions are shown in Figure 6.4. Figure 6.4(a) displays the trading volumes of the call and put options on the S&P500 index over the period from March 2000 to February 2001, while Figure 6.4(b), of which the data is taken from Reference Ederington and Guan (2002), shows the trading volumes of options on S&P500 Futures over the period from January 1988 to April 1998. They are common in three aspects: (1) The call and put volumes are higher close to ATM. (2) The total volume of put options is larger



(a) (b)

Figure 6.4: Empirical trading volumes plotted against moneyness (K/S^t). Call and put volumes are denoted by a ■ line and a ▲ line respectively. (a) Volumes of options on the S&P500 index over the period from March 2000 to February 2001. The minimum time to maturity is 0.1 year. (b) Average daily volumes of options on S&P500 Futures over the period from January 1988 to April 1998 and with time to maturity 13 to 26 weeks. Notice that the two data sets are different in moneyness range.

than that of call options. (3) The total volumes of ITM options are much smaller than those of OTM options, with those of deep ITM options being negligible.

To the best of our knowledge, little is known about the fraction of the different types of speculator in real markets. In this section, we analyze the volume distributions generated by the different types of speculator adopted in our microsimulation model. In each numerical experiment we consider only one type of speculator who trades together with arbitrageurs in equal fractions. We let all these directional speculators' expected prices and the volatility speculators' price fluctuation levels change over time, following the general process represented by Equation (A.2) and Equation (A.3) in Appendix A (for the specific forms and corresponding parameter values, see Qiu et al. (2010c)).

Figure 6.5 displays the trading volumes obtained if all the speculators in the simulations are of a specific type. The volume distributions in the case that all the speculators are SD traders are displayed in Figure 6.5(a), which have the same characteristics as the empirical distributions shown in Figure 6.4. If all the speculators are DSPR traders, we obtain trading volumes shown in Figure 6.5(b). They are low at ATM and high at ITM and OTM, and therefore not in line with the empirical observations. In the case that all the speculators are BSPR traders, the volumes are low at ITM and OTM, but high at ATM as well as deep ITM and OTM, as shown in Figure 6.5(c). They also do not agree with the empirical distributions. Only the SD speculators' trading volumes are in line with those observed in real markets. This suggests that the SD traders, rather than other types of speculator, are indeed the dominant speculative traders in real markets. This is in agreement with the findings reported in the empirical study by Ederington and Guan (2002) and further confirms the robustness of our findings regarding the mechanism underlying the volatility smile phenomenon, discussed in the previous chapter.

6.4 Conclusions

Heterogeneous speculative traders, such as DSPR and BSPR speculators, when trading together with SD speculators, induce competing effects with regard to the shape of the volatility smile. In particular, SD and DSPR traders have opposite effect with regard to the skewness of the IV curve, while SD and BSPR traders have opposite effect with regard to the level and convexity of the IV curve. Our analysis of trading volumes suggest that these traders are not the dominant speculators. This is in agreement with empirical findings.

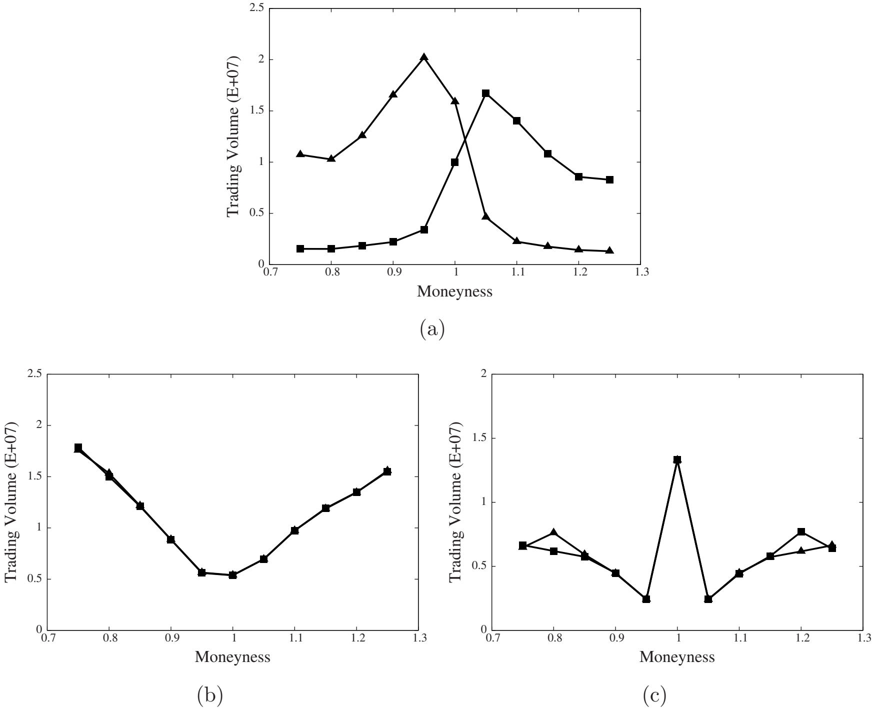


Figure 6.5: Trading volumes obtained if all the speculators in the simulation are of a specific type. Call and put volumes are denoted by a ■ line and a ▲ line respectively. (a) Simple directional traders. (b) Directional spread traders. (c) Butterfly spread traders. The fractions of each specific type of speculators and arbitrageurs are both 50%.