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CHAPTER 12

MARKETMAKING IN OPTIONS: PRINCIPLES AND IMPLICATIONS

*William L. Silber**

12.1 INTRODUCTION

Focusing on a single price that balances supply and demand has been enormously helpful in identifying underlying forces of market equilibrium. In keeping with this tradition, the arbitrage models of the options pricing literature focus on an equilibrium price to isolate the underlying determinants of an option's fair value. For the most part, these discussions ignore the structure of markets, taking for granted that somehow the interested buyers and sellers find their way to the marketplace and transact at the equilibrium price.

Although this simplification is appropriate when trying to evaluate the fair value of an option, in practice it is not so easy to bring buyers and sellers together. To help solve this problem, at the center of most securities markets, including options markets, a marketmaker emerges who stands

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ready to buy from the public at a bid price and to sell to the public at an offer price. By continuously quoting bids and offers, a marketmaker provides liquidity, and thereby facilitates the process of exchange. In particular, an investor wishing to sell an option immediately is always able to sell to the bid of a marketmaker and an investor wishing to buy immediately can always buy from the offer of a marketmaker. In the process of providing liquidity to market participants, marketmakers earn a profit based on the spread between the bid and offer prices and the volume of trading.

To those of us who have never actually engaged in marketmaking, the process by which a marketmaker arrives at a bid and offer quote, as well as the forces leading to revisions in quotations, have always been somewhat of a mystery. This is unfortunate because the marketmaker's bid-asked spread is a major component, along with commissions paid to a broker, of the cost of transacting. Since marketmakers play a major role in all types of options trading, our main objective is to understand the behavior of these marketmakers and to see exactly what determines the cost of transacting.

Section 12.2 describes the organizational structure of options markets, including an overview of the role of marketmakers in exchange traded options as well as in the more traditional over the counter (OTC) markets. Section 12.3 focuses on the optimizing behavior of marketmakers themselves, with special reference to the differences between marketmaker behavior for derivative securities such as options, versus marketmaking more generally. The remaining sections deal with guidelines used by options marketmakers to help quote bids and offers, including arbitrage and volatility relationships, and the practical problems confronting the marketmaker. The final section focuses on the investor's perspective: how should public traders respond to transactions costs?

12.2 MARKETMAKERS AND MARKET STRUCTURES

Before the Chicago Board Options Exchange (CBOE) came to life in 1973, all options were traded in the over the counter market. In this environment, various securities firms acted as marketmaking dealers, quoting bids and offers on puts and calls on individual stocks. An individual or institution wishing to buy or sell options would usually contact a brokerage firm to act as agent to buy from or sell to one of the option dealers. The cost of transacting included a commission paid to the broker and the expected bid-ask spread uncovered in the marketplace (which is a function, in part, of the cost of searching for the highest bid and lowest offer among competing marketmakers).

Over the counter trading continues to flourish in a number of options markets, including most prominently, Treasury securities, foreign exchange, gold, silver, oil and other physical commodities. In most cases, the marketmaking dealers in these options are the very same firms that are established dealers in the underlying asset. Thus, many of the commercial banks and investment banks that are primary dealers in government securities also make markets in options on specific Treasury securities. Similarly, the banks that deal in foreign exchange are the largest marketmakers in OTC foreign exchange options. And finally, the major bullion and oil trading firms are the primary marketmakers in options on these commodities.

Perhaps the single most important development in options markets was the establishment of exchange trading of options in 1973. The Chicago Board Options Exchange, an offshoot of the Chicago Board of Trade, applied the principles of standardized contract terms from futures markets to options. The CBOE introduced standardized strike prices and expiration dates for options on equities, where the underlying equities were listed for trading on the New York Stock Exchange or the American Stock Exchange. The CBOE's trading mechanism is a mixture of the specialist system adapted from the securities exchanges and a competitive marketmaker system adapted from futures markets. In particular, an employee of the CBOE coordinates an open auction and represents public limit orders much as would a specialist on the New York Stock Exchange. In addition, numerous "local traders" act as marketmakers by quoting bids and offers in the same trading pit, much as would traders on the futures exchanges.

Exchange trading of options accomplished a number of objectives. The centralized order flow reduced transactions costs by eliminating the search costs of uncovering the best bid and offer in over the counter trading. Standardized contract terms expanded the order flow to the marketplace, reducing the competitively determined bid-asked spread.[1] Finally, competing marketmakers emerged to offer continuously quoted bids and offers that facilitated immediate execution of public orders.

[1]See Demsetz [1968] for the first discussion of bid-asked spreads and why larger volume of trading reduces the spread.

The success of the CBOE's option trading induced other exchanges to sponsor trading in equity options, including the American Stock Exchange, the Pacific Stock Exchange, the Midwest Stock Exchange, the Philadelphia Stock Exchange and eventually even the New York Stock Exchange. Although most of these securities exchanges organized trading along lines of the specialist system, rather than following the CBOE's competitive marketmaker approach, the exchanges virtually eliminated over the counter trading in puts and calls on individual stocks. OTC trading in options was reserved for those equities that did not qualify for exchange listing, usually because the underlying stocks were too thinly capitalized. Thus, it seems that standardization of contract terms and centralized order flow are the key elements to the success of exchange options trading.[2]

Exchange trading of futures options was introduced in 1982.[3] Options on traditional futures contracts such as wheat, corn and soybeans as well as options on financial futures such as Treasury bonds, Eurodollars and stock indices now trade on the nation's futures exchanges. The trading mechanism for futures options is identical with the underlying futures contracts: an open outcry auction with competing marketmakers (sometimes called scalpers) freely quoting bids and offers.

Trading in futures options has been extremely successful, but it has not supplanted OTC options on the underlying commodities. As mentioned above, OTC options on Treasury bonds, gold, silver and crude oil trade actively alongside options on futures contracts. Although trading data do not exist for any OTC options, it is generally agreed that the volume of foreign exchange OTC options, for example, far exceeds the exchange-traded variety. There are a number of reasons for the success of OTC options on commodities. Hedgers in commodities frequently require customized strikes and expiration dates to reduce effectively their risk exposure. More importantly, marketmakers in OTC commodity options will frequently quote bids and offers that are good for much larger volume than the quotes of their exchange traded counterparts. Thus commercial hedgers who frequently must transact in large size, often prefer to execute trades in OTC

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[2]It should not be surprising that the specialist system succeeded just about as well as the competing marketmaker system. The specialist is, after all, a marketmaker as well as auctioneer. The specialist quotes bids and offers that provide liquidity; potential competition from other exchange members keeps the specialist's quotes fair.

[3]Options on agricultural commodities were banned in the United States by the Commodity Exchange Act of 1936. The Commodity Futures Trading Commission, established by Congress in 1974 to replace the Commodity Exchange Authority, authorized a pilot program in options on futures contracts in 1982.

commodity options rather than in futures options listed on the various exchanges. The disadvantages of the OTC options are costly search for the highest bid and lowest offer as well as the non-negotiability of OTC options. Hedgers must balance these considerations in determining where to do their options business.

12.3 MARKETMAKER BEHAVIOR FOR DERIVATIVE INSTRUMENTS

We have just seen that marketmakers play a central role in all types of options trading, including both the OTC and exchange-traded varieties. Since marketmaker quotations of bids and offers on options are a major determinant of transactions costs, it is useful to explore in somewhat greater detail marketmaker decision rules. An earlier study of marketmaker behavior in the competitive auction of futures exchanges (see Silber [1984]) provides a useful perspective on marketmaker activity. The overriding principle is that marketmakers provide the service of immediate execution of public orders by continuously quoting bids and offers. Thus a broker who enters the futures pit with a market order to buy can "lift the offer" of a marketmaker; a broker who has a market order to sell can "hit the bid" of a marketmaker. The marketmaker's objective is to sell at the offer what was bought at the bid and vice versa. More generally, the marketmaker's objective is to turn over inventory and earn the spread between bid and offer prices, rather than speculating on the direction of equilibrium price movements. In point of fact, the risk of change in the equilibrium price while the marketmaker temporarily has a nonzero inventory (because a bid has already been hit or an offer lifted) is one of the factors for which the marketmaker is compensated.

One of the skills required of a successful futures marketmaker is the ability to distinguish transient from permanent changes in order flow. In other words, the marketmaker must distinguish order flow which signals a change in the equilibrium price of the asset from order flow which will be reversed shortly, leaving the equilibrium price unchanged. In somewhat more practical terms, the marketmaker continuously assesses the probability of his or her bid being hit or offer lifted. The marketmaker revises the level of quotes whenever the flow of orders tends to be one-sided, i.e., whenever buyers or sellers predominate. Since marketmaking is more art than science, it is impossible to provide a simple rule prescribing when quotes should be revised up or down.

A marketmaker in options, whether it is options on futures, physicals, individual equities or index options has a similar set of objectives and requires a similar set of skills. One potential problem confronting an options marketmaker is the relatively sparse order flow usually experienced for any particular put or call. This makes it difficult for the marketmaker to estimate the equilibrium price. As a response, the marketmaker could quote a very wide bid-asked spread to compensate for the uncertainty and the price risk of the marketmaker's inventory. This is not only detrimental to the marketmaker because of the risk exposure, but it is also bad for the customer since wide bid-asked spreads imply large transactions costs.

In this context, the saving grace of options is that they are derivative securities so that their price movements are related directly to some underlying asset. Thus, an options marketmaker who buys call options because his or her bid was hit can offset the risk exposure of the unbalanced inventory position by selling short the underlying asset. Alternatively, if the marketmaker's bid for puts had been hit he or she can buy the underlying asset to offset risk. If the market for the underlying asset is liquid, so that the marketmaker can buy or sell sufficient quantities without inducing adverse price movements, the risk exposure could be hedged relatively cheaply, leading to a reduction in the bid-asked spread on the option. In section 12.5 below we will return to this discussion to show by specific example how the options marketmaker hedges in the underlying asset.

The options marketmaker can also offset risk exposure by buying or selling other options. For example, if the marketmaker's bid was hit for at-the-money calls on asset x expiring three months from now, a subsequent sale of at-the-money calls on asset x expiring four months from now would offset much of the marketmaker's inventory risk. Although order flow for any particular strike price and expiration date might very well be sparse, the order flow for all options on a particular underlying asset is much larger. Because options are derivative assets, all options on the same underlying asset are very close substitutes for each other. Marketmakers take advantage of this relationship to reduce their inventory risk. In the process, competition reduces the bid-ask spread quoted for each particular option.

It is interesting to note that the position of options marketmakers is a special case of marketmakers in thin securities whose returns are just highly correlated. A dealer in thin securities, such as CDs of small banks, can overcome the problem of sparse order flow in any particular issue by simultaneously making markets in many of these closely-related thin issues, e.g., by making markets in *all* small bank CDs. The dealer can then make a better informed estimate of the true equilibrium price of the generic security (small bank CDs), leading to a much narrower bid-asked spread than would be justified by the sparse order flow of each issue.[4] Options marketmakers, however, should be better off than these CD dealers because derivative securities such as options have closer price relationships with each other and the underlying asset than the substitute relationships among securities whose returns are highly correlated.

12.4 MARKETMAKER GUIDELINES: SIMPLE ARBITRAGE RELATIONSHIPS

To see how options marketmakers take advantage of the interrelationship among options in quoting bids and offers, we focus attention on some well-known arbitrage relationships. In particular, we will describe how market-makers use put-call parity and butterfly spreads to help in the marketmaking process. Although these are sometimes considered complicated relationships, they can be illustrated fairly simply. Along the way we will show that in the process of exploiting these arbitrage relationships, the marketmaker acts as the "options arbitrageur" of classical options theory. Thus, in addition to determining bids and offers we can also show how the market-maker influences the structure of options prices.

The best way to proceed is by way of specific examples. The simplest illustrations occur with options on futures contracts. This is so for two reasons: (a) options on futures trade alongside the underlying futures contract so that arbitrage is relatively inexpensive and easy for any member of the exchange; (b) since futures contracts require only margin deposits rather than a cash outlay, the examples can avoid the borrowing and lending component of the arbitrage relationships.

To provide a concrete framework for our examples, we assume that our marketmaker is a member of the New York Mercantile Exchange (NYMEX) and makes a market in crude oil options. The principles that emerge, however, are valid for all types of futures options. During the first half of 1988 the crude oil options market traded a daily average of about

[4]See Garbade [1982, p. 500] for more details of how a marketmaker in small bank CDs gains information by dealing in a number of such issues.

20,000 contracts. This was the most active nonfinancial futures option contract in the United States. On any particular day, approximately 50 members of NYMEX crowd into the crude oil options pit, which is located approximately 15 feet from the crude oil futures pit. Of these traders, about half are brokers who execute orders for off-floor hedgers and speculators, such as oil refiners, commercial users and brokerage houses; the other half are marketmakers trading for their own accounts or on behalf of larger marketmaker organizations.

Crude oil options are listed for trading in six consecutive expiration months. The specific strike prices listed vary with the historical price range of the futures contract; recently at least 8 different strikes have been the norm. Table 12–1 shows that on June 15, 1988, options were listed for expiration in August 1988 through January 1989 (futures contracts, by way of contrast were listed for June 1988 through July 1989). Strike prices (in the extreme lefthand column) ranged from $12 to $21 per barrel of oil. For each expiration month the table lists a column for puts and a column for calls, and for each type of option it lists a column for the settlement price ($P) and a column for the volume traded (vol). At the bottom of the table

TABLE 12–1
Crude oil options prices and trading volume for June 15, 1988

	August 1988				*September 1988*				*October 1988*			
	Puts		*Calls*		*Puts*		*Calls*		*Puts*		*Calls*	
Strike Price	*$P*	*Vol*	*$P*	*Vol*	*$P*	*Vol*	*$P*	*Vol*	*$P*	*Vol*	*$P*	*Vol*
$12	-	-	-	-	-	-	-	-	-	-	-	-
$13	-	-	-	-	-	-	-	-	-	-	-	-
$14	-	-	-	-	-	-	-	-	-	-	-	-
$15	.03	319	1.65	-	.10	172	1.75	-	.16	406	-	-
$16	.11	3,099	.74	380	.30	2,381	.95	-	.39	229	1.06	2
$17	.52	2,840	.14	2,196	.74	1,515	.39	607	.83	74	.50	17
$18	1.40	267	.03	2,580	1.50	250	.15	1,729	1.57	9	.24	237
$19	2.38	100	.01	806	2.39	-	.04	532	2.44	-	.11	32
$20	-	-			3.37	-	.02	410	-	-	.05	7
$21	-	-					.01	99	-	-	.02	-
Futures Price		$16.62				$16.65				$16.68		

there is a line for the settlement price of the futures contract for that particular month. Note that the total volume of options traded on June 15, 1988 was about 25,000 contracts, or just slightly more than the average daily trading volume for 1988.

The data listed in Table 12–1 are the settlement prices of the options at the close of business on June 15, 1988 and the number of contracts traded for each option on that day. For example, next to the 16 strike price under the August column, the price of the puts is listed as .11 and the price of the calls is listed as .74. Thus, the so-called August 16 puts cost 11 cents per barrel and the August 16 calls cost 74 cents per barrel. Since each contract is for 1,000 barrels of oil, that means the total cost of an August 16 put is $110.00 (.11 × 1,000) and the total cost of the August 16 call is $740.00. For our discussion purposes, we will always use the per barrel price since that is the way these options prices are quoted (this is similar to stock options whose prices are quoted per share even though the standard contract size is for 100 shares).

The first thing to notice about the table is that the volume of trading is concentrated in the "front months", i.e., August and September. In

TABLE 12–1, continued

	November 1988				*December 1988*				*January 1989*			
	Puts		*Calls*		*Puts*		*Calls*		*Puts*		*Calls*	
Strike Price	*$P*	*Vol*	*$P*	*Vol*	*$P*	*Vol*	*$P*	*Vol*	*$P*	*Vol*	*$P*	*Vol*
$12	-	-	-	-	-	-	-	-	-	-	-	-
$13	-	-	-	-	-	-	-	-	-	-	-	-
$14	-	-			.10	4			.15	25		
$15	..21	765			.27	160			.32	-	-	-
$16	.47	2,211			.54	20			-	-	-	-
$17	.93	300	.62	-	1.01	23	.71	1	1.08	-	-	-
$18	1.60	11	.29	10	1.67	2	.37	5	-	-	-	-
$19	-	-	.15	7	-	-	.21	20	-	-	-	-
$20	-	-	.08	702	-	-	.13	5	-	-	-	-
$21	-	-	.04	-	-	-	.07	-	-	-	-	-
Futures Price		$16.69				$16.70				$16.69		

particular, of the 25,582 contracts traded on June 15, 1988, 12,587 were in August puts and calls and 7,695 were in September puts and calls. Moreover, of these 20,273 August and September options, almost all were concentrated in the 15 through 19 strike prices. Closer examination reveals that the most active puts and calls are the at-the-money or near out-of-the-money contracts. In particular, the August futures contract settled at $16.62 and September futures at 16.65. The most active puts were the 16 strike followed by the 17 strike and then the 15 strike. The most active calls were the 18 strike followed by the 17 and then the 19 strikes. These patterns of trading volume are typical of crude oil options generally as well as of all types of options.

Let us turn now to some basic pricing relationships. Settlement prices released by the exchange each day (recorded in Table 12–1 for June 15, 1988) are set to reflect the bid and offer represented in the pit at the close of trading. As described in section 12.3 above, a marketmaker quotes a bid and offer to keep a balanced inventory. This is a reasonable task for the actively traded puts and calls in August and September, since there is sufficient order flow to judge where the equilibrium price is. But for some of the options listed in Table 12–1 the volume of trading is relatively low (e.g., the August 19 puts traded only 100 contracts the entire day) or is nonexistent (e.g., the September 16 calls). This would seem to make the marketmaker's task difficult if not impossible, not just at the close of business, but throughout the trading day.

Applications of Put-Call Parity

One of the simplest concepts used by the marketmaker to quote bids and offers on infrequently traded options is put-call parity. Even without knowing the formal mathematical proofs, the marketmaker is aware that buying one put and buying one future is equivalent to buying one call at the strike of the put option. Similarly, the marketmaker is aware that buying one call and selling one future is equivalent to buying one put at the strike price of the call option. Thus, the marketmaker can use these so-called synthetic calls and puts to judge where the appropriate quotes should be.[5]

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[5]The proof that long a call and short a future is a synthetic long put as well as the proof that long a put and long a future is a synthetic long call can be verified by constructing a payoff table for the synthetic position and the outright position on expiration. They will turn out to be the same. The next footnote has a specific example.

Here is a specific example. Suppose we are near the close of trading on June 15, 1988 and a broker enters the pit and asks for a market in September 16 calls. They have not traded all day so there is no clue about pricing from order flow in the calls. On the other hand, September 16 puts have traded over 2,000 contracts and are now quoted at .29 bid, offered at .31 (the midpoint, .30, is the settlement price on the September 16 calls). With September futures trading at 16.65, the marketmaker realizes that if he or she can buy one September 16 call at .94 and sell one September future at 16.65, the resulting position will be long a synthetic 16 put at .29. This follows from the payoff at expiration to the long call at .94 combined with a short future position at 16.65.[6] The only difference is the synthetic put requires an outlay of $940 per contract while buying the put outright would require an outlay of $290. Interest on the $650 difference until expiration of the September option (on August 12, 1988) at 7 percent amounts to approximately $7.50. Thus, the marketmaker is likely to bid .93 for the 16 call rather than .94 (to cover the interest expense). A similar line of reasoning suggests that if the marketmaker can sell the call at .96 and buy the future at 16.65, the resulting position will be short a synthetic 16 put at .31. This time interests works in the marketmaker's favor since he or she takes in .96 (rather than .31). Thus the call might be offered at .95.

The outcome of the story is that the broker asking for a quote on September 16 calls will hear .93 bid, offered at .95 or .94 bid, offered at .96 (if interest is ignored). In point of fact, uncertainty over where the marketmaker will sell the futures contract (it could easily be 16.65, 16.64 or, less likely, 16.66) will widen the quote somewhat—.93 bid, offered at .96 is the most likely market for the September 16 calls.

Now let's see what the marketmaker does in response to a particular transaction. Suppose the broker sells one call to the marketmaker at .93 and the marketmaker sells a futures contract at 16.65, the marketmaker is long a synthetic put with a 16 strike price at a price of .28. The marketmaker could then try to offset completely the risk of the long synthetic put by

[6]Here is the numerical proof of this statement. If the future expires at $16.00, the call expires worthless—losing $.94. The short future at $16.65 gains $.65. Thus the position loses $.29. If the future expires anywhere above $16.00 the position still loses *exactly* .29 (e.g., at 16.20 the call is worth .20 so the loss on the call is only .94 - .20 or .74, but the profit on the short future is only 16.65 – 16.20, or .45; the total loss is .74 – .45 or .29). If the future expires anywhere below 16.00, the call expires worthless, losing .94 but the short future from 16.65 provides gains penny for penny with the decline in the futures. For example, at 15.71 the gain is 16.65 minus 15.71 or .94, so the net loss is zero. At 15.50 the short future is worth 16.65 minus 15.50 or 1.15 minus .94 for a net profit of .21. Notice that these last two cases have the same payoff as long a put with a 16 strike that costs .29, i.e., at 15.71 the long put position breaks even while at 15.50 it makes .50 – .29 or .21.

selling a put outright. We started off by noting that the market for September 16 puts was .29 bid offered at .31. Our marketmaker can sell a put simply by hitting a bid of .29, locking in a profit of .01 (the .29 sale of the put minus the .28 cost of the synthetic put), or $10 per contract. Alternatively, the marketmaker might choose to offer the put at .30 (bettering the existing offer of .31), hoping that some anxious buyer bidding .29 will step up and buy the put at .30; in this case the marketmaker locks in a profit of .02, or $20 per contract. Notice that once the marketmaker has bought one call, sold one future and sold one put, the position, known as a reverse conversion or reversal, is riskless. No matter what happens to the price of the futures contract, the marketmaker's $10 or $20 profit remains.[7]

Alternatively, suppose the broker had bought a call from the marketmaker at .96. The marketmaker then buys a future at 16.65 and tries to buy a put at .30 (bettering other bids of .29). If the marketmaker is successful, the short call-long put-long futures position, known as a conversion, is riskless and locks in a profit of $10 (the difference between selling the synthetic put at .31 and buying the put outright at .30). No matter what happens to the price of the futures contract the $10 profit remains.[8]

It is clear that the principle of synthetic puts and calls allows the marketmaker to quote bid and offer prices for options that have little or no order flow. The consequence for pricing relationships among options is known as put-call parity. More specifically, unless synthetic puts are valued at the same price as outright puts and unless synthetic calls are valued at the same price as outright calls (all adjusted for interest costs), a riskless profitable transaction is available. Because of low transactions costs and expertise in executing trades, marketmakers respond quickly to such riskless arbitrages. Thus, price quotations always reflect the principles of put-call parity. That is not to say such riskless transactions do not take place—they most certainly do. But they are reserved for marketmakers with low transactions costs who put in the time and effort to monitor continuously order flow in the options and futures pits.

[7]The only risk exposure facing the marketmaker is when the futures contract expires at or near the strike price. Under those circumstances, the marketmaker does not always know whether the short put (in this case) will be exercised. In particular, even if the option is slightly in the money, it may not be exercised. The option holder may not want the futures position that comes with exercising the option. This risk of not knowing a position can induce marketmakers to limit the number of such positions they put on.

[8]In both conversions and reversals the marketmaker must worry about financing variation margin payments on the short or long futures position. This can be accomplished by selling or buying e^{-rt} futures for each conversion or reversal rather than hedging with futures on a one to one basis.

The settlement prices in Table 12–1, in fact, reflect put-call parity within a .01 or .02 discrepancy.[9] The $10 or $20 profit opportunities are well within the usual bid-asked spread. Thus, they do not represent riskless profitable transactions for public customers. If settlement prices did indicate that larger profits were possible, it probably means an error was made in recording those prices.

Applications of Butterfly Spreads

A glance at Table 12–1 reveals an apparently serious problem for the marketmaker. Some strike prices—even for the active August and September expirations—have no volume of trading for either puts *or* calls. How, then do marketmakers quote bids and offers when confronted by a broker's request? One response is for the marketmaker to quote a very wide bid-asked spread, leaving plenty of room for error concerning the true equilibrium price. This is the usual response in any market. But with options, the marketmaker has a handy reference point, using so-called butterfly spreads, that can help sharpen the precision of the marketmaker's quotes. The best way to understand the process is by way of specific example.

Suppose a broker enters the options pit and asks for a market in October 21 calls. Table 12–1 shows that there was zero volume in October 21 puts and calls, so the marketmaker has no help from order flow or put-call parity. In point of fact, a marketmaker only needs to know where the October 19 call and October 20 call are quoted in order to quote a market in the 21 calls. Assume, as suggested by the settlement prices, that the 19 calls are .10 bid, offered at .12 and the 20 calls are .04 bid, offered at .06. The marketmaker would then be willing to quote the 21 calls as .01 bid, offered at .03, or to be on the safe side, .01 bid, offered at .04. The marketmaker is comfortable with such a quote, especially if the broker hits the .01 bid. In that case, if the marketmaker buys a 21 call at .01 he or she

[9]Put-call parity is often stated in the following way: the price of the synthetic long futures contract—long a call, short a put—must equal the price of the futures contract. In Table 12–1 you can verify these relationships by adding the price of the call to the exercise price of the option, subtracting the price of the put, and comparing that number with the settlement price of the futures contract. In formal terms, if C is the call price, P is the put price, F is the price of the underlying futures contract, X is the exercise price, r is the risk free interest rate and T is the time to option expiration, then put-call parity implies the following price relationship:

$$C - P = e^{-rT}(F - X).$$

would bid aggressively for a 19 call, perhaps bettering the existing .10 bid and buying from an anxious seller at .11. At the same time the marketmaker tries to sell two 20 calls at the .06 offering price. If the marketmaker is successful, the resulting position is long one 19 call, long one 21 call and short two 20 calls, with the total dollar outlay of zero (the .11 plus .01 cost of the 19's and 21's is offset by the sale of two 20's at .06).

This position is known as long a butterfly spread, where the 19 calls and 21 calls are called the wings. The payoff to a long butterfly has a minimum of zero (if the futures contract settles on expiration below 19 or above 21) and a maximum of $1.00 per butterfly spread (the payoff is 1.00 if the futures contract settles *exactly* at 20, so that everything is worthless except the 19 call which has a value of $1.00). Clearly, the marketmaker would eagerly incur a cost of zero to put on a position that has a zero chance of losing money but could wind up making a substantial profit. Thus the marketmaker is delighted to purchase the 21 calls at .01, especially if the order flow for the 20 calls suggests that sales at .06 are reasonable. The marketmaker is less happy about selling those 21 calls at the .03 offer since if he or she establishes a short butterfly position (short the wings and long the center) the payoff is a large loss if the option contract expires when the future is at the center strike. Nevertheless, if the option is far away from the current price of the underlying and there is not that much time to expiration left, a sale at .03 is reasonable. Just to be sure, however, we tacked on a .01 to the offer price which makes for a safer sale of the 21 calls at .04.

Butterfly spreads usually cannot be put on at zero cost. Only a marketmaker with low transactions costs who continuously monitors the market can hope to do it—and even then only if the center of the butterfly is relatively far away from the current price of the underlying futures contract, so that there is relatively little chance that the butterfly will produce a profit. This was the case in our example with the 19-20-21 butterfly (the futures contract was trading at 16.65). In all other cases, marketmaker competition for long butterfly spreads will lead to a positive cost of every butterfly combination.

The implications of this very last point are rather interesting as far as the structure of options pricing is concerned. The fact that butterfly spreads should, in general, cost something means that for any three options that have equally spaced strike prices, the value of the middle option is always less than a simple average of the other two. A quick review of Table 12–1 will reveal the accuracy of this statement—both for puts and for calls. A formal proof of this point and other "butterfly" price relationships is found in Chapter 2.

Before turning to how marketmakers use some of the sophisticated options technology developed in recent years, let's take one more step in the simple arbitrage process and examine the role of over the counter marketmakers. Our discussion in section 12.2 above suggested that for assets such as Treasury bonds, foreign exchange, gold, silver, oil and others, a thriving market exists for both exchange-traded and OTC options. OTC marketmakers have one major advantage over their exchange-based counterparts: OTC marketmakers see order flow in options that marketmakers on the exchange floor do not have access to. Thus, a so-called upstairs marketmaker can often buy or sell OTC options and then lay off some or all of the risk by selling or buying exchange-traded options with similar strikes and expiration dates. Thus OTC marketmakers can and do put on options positions that are almost, but not quite, riskless arbitrage positions. Since OTC customers are likely to search among OTC marketmakers for the best bid and offer, competition and arbitrage should bring the prices of OTC options into line with exchange-traded options. Unfortunately, there are no data available on OTC options to substantiate this proposition.

12.5 ADVANCED MARKETMAKER TECHNOLOGY: DELTAS AND MODELS

Although conversions, reversals and other arbitrage-type relationships provide important guidelines for options marketmakers, exclusive reliance on such techniques leaves the marketmaker at the mercy of order flow in options to offset inventory risk. This is less than desirable considering the sparse order flow problem in most options. As pointed out in section 12.3 above, however, the fact that options are derivative instruments leaves open the possibility of hedging in the underlying asset. Marketmakers who take advantage of this possibility will be able to distinguish themselves from other traders (see Silber [1984]) by quoting bids and offers continuously and over a wide range of options. As usual, we illustrate these principles first by way of specific example, and only then introduce formal option pricing models into the decisionmaking process. To set the stage for the model-based analysis, however, our example uses some of the formal terminology of the options pricing literature.

The first part of our discussion shows how hedging in the underlying asset is designed to protect the marketmaker's option position from small movements in the price of the underlying asset. The next step describes the risks that remain in these hedged positions. Finally, we describe how marketmakers use formal option pricing models to help implement the entire process.

Delta-Neutral Hedging

Suppose a broker enters the crude oil options pit on June 15, 1988 and asks for a market in the September 17 calls. Although approximately 1,500 of these calls and 600 September 17 puts traded on this day, order flow is often quite sparse at any particular point in time. The bulk of trading is usually done during the first and last hour of the day, rather than continuously. Thus, although marketmakers may know where the puts and calls have been trading, fifteen minutes can easily elapse before another order to buy or sell this particular option enters the pit. A marketmaker who relies only on conversions and reversals or butterflies will be reluctant to quote a market. In particular, if the marketmaker's bid is hit or offer is lifted he or she is long or short options, with the associated price risk should crude oil futures move up or down. However, a marketmaker who knows how the price movement in the 17 calls is related to the price movement in the futures contract, can buy or sell futures in the proper ratio in order to neutralize the inventory risk of the options position.

Based on experience, a good options marketmaker knows that the price of an at-the-money futures option moves about half as much as the price of the underlying asset. More specifically, the so-called *delta* of an at-the-money call is approximately plus .5, while the delta of an at-the-money put is approximately minus .5, i.e., the call moves half as much in the same direction as the future, while the put moves half as much in the opposite direction. Armed with this information, when the broker enters the options pit and asks for the market in September 17 calls, the marketmaker checks the September futures contract to see where it is trading. Since order flow in futures is much more dense than options, the most recent trade in futures is likely to be only a few seconds old. If the September futures contract is trading at 16.65, the marketmaker would probably quote the September 17 call at .38 bid offered at .40 (see Table 12–1 where .39 is listed as the value of the 17 call when September futures are trading 16.65). If the broker sells ten contracts to the marketmaker, the marketmaker immediately orders a sale of five futures contracts (since the delta is approximately .5), hoping the sale is completed at a price of 16.65. This sale would then offset the price risk of the marketmaker's long call position. For example, if the price of

September futures subsequently falls to 16.55 and the value of the September 17 calls falls to .34, the .05 loss on the ten calls in the marketmaker's position is offset by a gain of .10 on the five contract short position in futures. This is called *delta-neutral hedging* because the proper number of futures used to offset the risk exposure of the option position is based on the delta of the option.

The ultimate objective of the marketmaker is, of course, to sell at the offering price the calls that were just bought on the bid side of the market. Recall that the marketmaker always wants to buy at the bid and sell at the offer. The advantage of hedging in the underlying is that it allows the marketmaker to reduce inventory risk while bridging the gap between asynchronously arriving buy and sell orders for options. In a sense, the immediate sale of the five futures contracts is a surrogate for the immediate sale of the options contracts. Thus, if a broker subsequently enters the options pit and lifts the marketmaker's offer on the 17 calls, the marketmaker will buy back the futures contracts that were sold to protect the inventory.

It should be clear that as long as marketmakers are risk averse, a marketmaker who hedges inventory risk will be able to compete successfully against one who does not hedge, by quoting a narrower bid-asked spread. Recall from section 12.2 above that one of the major determinants of the bid asked spread is the risk exposure of the resulting inventory position. Hedging the options inventory in the more liquid futures market in a sense transfers the liquidity of the futures market to the options market. Thus, the customer is better off because the bid-asked spread is narrower, and so is the marketmaker because inventory risk has been minimized.

A similar hedging strategy can be followed with puts except this time the marketmaker buys futures when buying puts and sells futures when selling puts. The reason is straightforward: puts decrease in value when the market rises, therefore, a long futures position is needed to offset the loss on a long put position as futures prices rise.

Risk in Delta-Neutral Portfolios

Offsetting the price risk of options inventory by delta-based purchases and sales of the underlying, produces a delta-neutral portfolio for the marketmaker. In particular, the value of the marketmaker's portfolio is insulated from the effects of small price changes in the underlying asset in either direction. Although this situation is preferable to a naked options position, the marketmaker is still at risk in a number of dimensions. First, a delta-neutral position that is long options (as in our example) will lose money over time because options are wasting assets. As the expiration date of the option moves closer, the value of the option above its intrinsic value declines. The dollar value of the decline in the option each day is called *theta*. Thus, a long options position loses theta (times the number of options in the position) each day, while a short options position gains theta each day.

This last point suggests that marketmakers should prefer delta-neutral positions that are short options because they earn the erosion in the value of the option over time. The problem, as usual, is that there is no such thing as a free lunch. Delta-neutral options positions are hedged for small movements in the price of the underlying asset, as suggested above, but not for large price movements. The problem arises because the delta of the option changes as the price of the underlying moves up and down. The change in delta per unit change in the price of the underlying is called *gamma*. If the marketmaker's portfolio is short options (either puts or calls) and he or she wishes to remain delta-neutral at all times (thereby avoiding a view of market price direction), the marketmaker must rebalance the hedge by buying futures when the market goes up and selling when the market goes down.[10] Thus, volatility in the underlying asset in conjunction with the gamma of an option imply that a delta-neutral position that is short options will lose money when the price of the underlying is volatile. On the other hand, a delta-neutral position that is long options benefits from price volatility. In particular, rebalancing a long delta-neutral options position requires selling futures when the market rises and buying futures when the market falls.[11]

It is interesting to note that theta and gamma tend to compensate for

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[10]An example of why rebalancing the hedge is necessary when the price of the underlying moves up and down, and why short options positions lose money in this case is as follows. Suppose the marketmaker is short ten at-the-money 17 calls and long five futures contracts at a price of 16.95. The position is delta-neutral because the delta of the 17 calls is .5 when the futures price is 16.95. As the price of the futures contract rises, say to 17.50, the calls become in-the-money and their delta rises, say to .6. The marketmaker must now buy one futures contract at a price of 17.50 to remain in a delta-neutral position. If the futures price then declines to where it was before, the marketmaker must sell out one futures contract at a price of 16.95 to remain delta-neutral. The end result is that the marketmaker's position is exactly where it was (long ten 17 calls and short five futures), except in the interim he or she has bought a futures contract at 17.50 and sold it at 16.95 for a loss of .55 (or $550.00).

[11]To prove this, see the previous footnote and recreate the example except this time assume the marketmaker is long ten 17 calls and short five futures.

one another. In particular, a delta neutral position that is long options loses money because of theta each day, but makes money when the market moves up and down because of gamma. On the other hand, a delta neutral position that is short options makes money because of theta each day, but loses money when the market moves up and down because of gamma. Nevertheless, marketmakers are not usually indifferent between these two characteristics. Theta erosion in the value of an option occurs fairly smoothly over time, while loses from gamma rebalancing can be large and discontinuous. The latter occurs when there is a sharp price movement in the underlying that prevents the marketmaker from continuously rebalancing the portfolio. This often occurs when there is a sharp jump or drop in price between the close of trading on one day and the opening on the following.

The implication of all of this is that marketmakers prefer ultimately to balance their portfolios by buying some options and selling others rather than by being net buyers or sellers of options versus futures. This reinforces the notion that marketmakers view delta-hedging in the underlying asset as a temporary substitute for an option transaction. More specifically, continuing our previous example, once our marketmaker has bought the September 17 calls and sold futures to hedge price exposure, he or she is likely to be a more anxious seller of options the next time around. Thus, if a broker asks for a market in the September 18 calls, the marketmaker might bid .14 and offer at .15, hoping that the relatively low offer is lifted by the broker. If the broker buys twenty-five of the 18 calls, the marketmaker would have to buy enough futures to be delta-neutral again. It just so happens that the delta on the 18 calls is about .20, so the marketmaker would buy back the five futures contracts that were sold to offset the marketmakers purchase of the ten 17 calls. Thus the marketmaker's position is long ten September 17 calls and short twenty-five 18 calls. This position is delta-neutral as before, but the theta-based loss associated with being long ten September 17 calls is more or less offset by the short position in the September 18 calls. Thus, the marketmaker can plan to earn the bid-asked spread without worrying about the erosion in the value of the options portfolio.[12]

[12]The marketmaker cannot relax completely with this position since theta, as well as gamma, change with the price of the underlying asset. Thus, the thetas (and gammas) of the long ten 17 calls and short twenty-five 18 calls are roughly in balance when the price of the underlying asset is about \$17.00. But if the price of the underlying jumps to \$18.00, for example, the short position in the 18 calls dominates the long position in the 17 calls. The marketmaker will then make money from theta erosion but lose money when the market is volatile because of gamma.

Using a Valuation Model

Our somewhat complicated example suggests that marketmaking in options requires more than just reading the balance of order flow in the options market. A fair amount of technical information—deltas, gammas and thetas—can be brought to bear on the situation. Marketmakers may rely on experience to assess some of these factors, but modern options pricing models, from the simple binomial to complicated modifications of Black-Scholes, are frequently utilized to help manage the options position of an active marketmaker. This is especially important because the sparse order flow of each individual option usually forces a marketmaker to become short and long options with many different strike prices and expiration dates. A formal model can keep track of portfolio deltas, gammas, thetas and more, with greater efficiency than even the most experienced marketmaker.

In a somewhat related vein, marketmakers frequently use option pricing models to help gauge the fair values of an option. The example of marketmaking presented above assumed that the futures price was 16.65, so that the value of the 17 and 18 calls were .39 and .15, as indicated by the settlement prices recorded in Table 12–1. But when the futures price moves, so does the price of the option that is likely to balance the flow of buy and sell orders. Marketmakers use experience and trial and error to move their quotes when the price of the underlying asset moves, but they also rely upon fair values derived from option pricing models to help in the quotation process. Moving quoted bids and offers to the proper level helps to avoid unwanted shifts in inventory (as would occur when bids that are too high are hit or when low offers are lifted).

Although there are a variety of option pricing models to choose from, any one can demonstrate how they contribute to marketmaking. Since we have been dealing with options on crude oil futures, let us illustrate our discussion with Black [1976] which models a European option on futures and forward contracts.

The model developed in Black [1976] generates the fair value of an option, defined as the option price which does not offer any riskless arbitrage opportunities, as a function of the price of the underlying asset, the strike price of the option, the number of days to expiration, the short term interest rate (until expiration) and some measure of the price volatility of the underlying asset. In addition, the model provides the delta, gamma and theta of the option, as well as *kappa* (sometimes called *vega*), which measures the sensitivity of the option price to a change in volatility (to be discussed below). Obviously, when the marketmaker is asked by the broker to quote a bid and offer for the September 17 call, it would be useful to have the fair value and the delta of the option as estimated by the model in Black [1976]. The fair value helps the marketmaker center the quotes and the delta prescribes the number of futures contracts required to hedge the position

In practice, using the model is both trivially easy and extremely difficult. The five items listed above as determining the fair value of an option can be fed into the computer, along with the formula from Black [1976], producing the option's price, the delta and so on, within seconds. The process is straightforward with four of the five items influencing the option's value: the price of the futures contract, the expiration date of the option, the short term interest rate and the strike price of the option are known with certainty at the time the option must be priced. The price volatility of the underlying asset, on the other hand, is a problem. It is a problem because the option's value depends on the price volatility of the underlying asset (defined as the annualized standard deviation of the percentage price change), from now until the expiration date of the option. Thus, in the case of the September 17 calls, it depends on the price volatility of crude oil futures between June 15, 1988 (the date of the price quote) and August 12, 1988 (the date September crude oil options expire). Although we will be able to calculate precisely what that was after the option expires on August 12, 1988, the marketmaker can only offer an estimate of price volatility on June 15, 1988.

Marketmakers use a variety of techniques to estimate volatility. One approach is to calculate historical price volatility over some previous period—10 days, 20 days, 30 days and so on and enter that value into the formula. This is tantamount to assuming that the best estimate of the market's volatility in the future is past volatility. Variations on this approach include statistically generated weighted averages of past price volatility that have been superior predictors of future volatility.

A popular alternative to historical volatility that is used by many marketmakers is the implied volatility of the option. The option pricing formula can produce the fair value of an option if given all five inputs, including volatility. Alternatively, if the price of the option is entered into the formula along with everything but volatility, the model generates a volatility number that is consistent with the other variables. This number is called implied volatility because it is the volatility that is implied by the price of the option.

Marketmakers who use implied volatility to generate fair values calculate implied volatility from options and futures prices at some earlier point in time, usually the previous day's settlement prices. These implied volatilities are then fed into the formula to generate fair values, deltas and so on for the current day.[13] Table 12–2 shows a sample marketmaker fair value table for June 16, 1988 for September crude oil options, based on the implied volatilities from the options and futures settlement prices of June 15, 1988. It is useful to review this table in some detail.

There are eight columns of option strikes, labelled September 13 through September 20, at the top of Table 12–2. The extreme left-hand column lists various prices of the September crude oil futures contract, ranging from $16.00 at the top of the page down to $16.95 at the bottom. Associated with each price is the fair value of the call and the put as well as the delta for each option. For example, under the September 13 column there are two columns of numbers, the left column is the price of the option, the right column is the delta. The first pair of entries in the column are the fair value and delta of the September 13 call when the futures price is 16.00 and the second pair of entries is the fair value and delta for the September 13 put when the futures price is 16.00, and so on. Thus the September 13 call has a fair value of $3.01 and a delta of .94, while the September 13 put has a fair value of $.04 and a delta of minus .05, when the September futures price is $16.00 (the put has a negative delta because its price moves opposite the future's price).

The remaining entries of Table 12–2 record the fair values and deltas for alternative futures prices. For example, look at the fair values for the puts and calls when the September futures contract has a price of 16.65. We see that the 15 and 16 puts and the 17, 18 and 19 calls have the same fair values as the settlement prices recorded in Table 12–1. This is not terribly surprising. The fair values in Table 12-2 were, in fact, based on the settlement prices in Table 12–1, including the settlement price of 16.65 for the September future. The only difference is the passage of one day in the option's life. However, one day's theta erodes fair value by less than one cent (theta is listed at the top of each column, e.g., $T = .005$ in the column

[13]Over the counter marketmakers have access to real time computer programs that recalculate implied volatility with each transaction. Most marketmakers would not revise their estimates of volatility so frequently.

for the 17 strike). In general, the fair value of the option does not have much overnight theta erosion until it has less than one month to expiration

The fair value table can be very helpful to the marketmaker in a number of ways. Recall that in our earlier example, the marketmaker estimated the delta of the 17 calls at .5 since the calls were "just about at the money." Table 12–2 shows that when the September future is 16.65 a more precise estimate of the delta of the 17 call is .41. Thus the marketmaker should have sold only four futures, rather than five, when buying ten 17 calls from the broker in order to be properly hedged.

The fair value table is also extremely useful at the opening of trading if the futures price changes substantially overnight. For example, if September futures open down .35 cents at 16.30 on June 16, 1988, and a broker asks for a market in the 17 calls right at the opening, the marketmaker sees from the table that based on yesterday's implied volatility the fair value would be .26. He or she might then quote the market as .24 bid, offered at .28. Thus, the marketmaker can use the fair value table as a guideline for centering bid and offer quotes. Without such help the marketmaker would have quoted a much wider bid-asked spread to protect against ignorance over where the true market really is. Note that it is quite normal for marketmakers to quote wider spreads at the opening of trading because they are less certain of where the balance in order flow will be. Although fair value tables help, they are only as good as the volatility entered into the pricing formula. Yesterday's implied volatility reflects yesterday's market environment. It may be the best estimate available for today, but it is only an estimate. Thus our example suggested a bid-asked spread of .04 for the opening quote rather than the more usual .02 spread, even with the help of the fair value table.

12.6 PERSPECTIVES ON VOLATILITY

Since volatility is the crucial unknown component to estimating fair values of options, it makes sense to examine the numbers somewhat more carefully. At the top of each strike price column in Table 12–2, the implied volatility underlying the fair value calculation is listed. For example, under the September 17 strike price $I = 20.46$ means that the implied volatility for that strike is 20.46%. In the column for the September 16 strike price, the implied volatility used is 21.80. Recall that these numbers for implied

TABLE 12–2
Fair value table for crude oil options (June 16, 1988)

Commodity: CRUDE 16.650
Rate: 7.500
Current Date: JUN 16 88

	SEP		*SEP*		*SEP*		*SEP*		*SEP*		*SEP*		*SEP*		*SEP*	
	X =	*13.00*	*X =*	*14.00*	*X =*	*15.00*	*X =*	*16.00*	*X =*	*17.00*	*X =*	*18.00*	*X =*	*19.00*	*X =*	*20.00*
	I =	*32.16*	*I =*	*28.61*	*I =*	*23.48*	*I =*	*21.80*	*I =*	*20.46*	*I =*	*21.61*	*I =*	*21.29*	*I =*	*24.16*
	V =	*0.004*	*V =*	*0.008*	*V =*	*0.014*	*V =*	*0.024*	*V =*	*0.026*	*V =*	*0.019*	*V =*	*0.010*	*V =*	*0.006*
	T =	*0.001*	*T =*	*0.002*	*T =*	*0.003*	*T =*	*0.004*	*T =*	*0.005*	*T =*	*0.004*	*T =*	*0.002*	*T =*	*0.001*
16.00	3.01	0.94	2.08	0.88	1.20	0.76	0.55	0.51	0.18	0.24	0.06	0.09	0.01	0.02	0.00	0.01
	0.04	–0.05	0.10	–0.11	0.21	–0.23	0.55	–0.48	1.16	–0.75	2.03	–0.90	2.98	–0.97	3.96	–0.98
16.05	3.05	0.95	2.12	0.89	1.24	0.77	0.57	0.53	0.19	0.25	0.06	0.10	0.01	0.03	0.00	0.01
	0.04	–0.04	0.10	–0.10	0.20	–0.22	0.52	–0.46	1.13	–0.74	1.99	–0.89	2.93	–0.96	3.91	–0.98
16.10	3.10	0.95	2.17	0.89	1.27	0.78	0.60	0.54	0.20	0.26	0.07	0.10	0.01	0.03	0.00	0.01
	0.04	–0.04	0.09	–0.10	0.19	–0.21	0.50	–0.45	1.09	–0.73	1.94	–0.88	2.88	–0.96	3.86	–0.97
16.15	3.15	0.95	2.21	0.89	1.31	0.79	0.63	0.55	0.21	0.28	0.07	0.11	0.02	0.03	0.00	0.01
	0.03	–0.04	0.09	–0.09	0.18	–0.20	0.48	–0.44	1.06	–0.71	1.90	–0.88	2.83	–0.96	3.81	–0.97
16.20	3.20	0.95	2.26	0.90	1.35	0.80	0.66	0.57	0.23	0.29	0.08	0.12	0.02	0.03	0.00	0.02
	0.03	–0.04	0.08	–0.09	0.17	–0.19	0.46	–0.42	1.02	–0.70	1.86	–0.87	2.79	–0.96	3.77	–0.97
16.25	3.24	0.95	2.30	0.90	1.39	0.81	0.68	0.58	0.24	0.30	0.08	0.12	0.02	0.04	0.00	0.02
	0.03	–0.04	0.08	–0.09	0.16	–0.18	0.44	–0.41	0.99	–0.69	1.81	–0.86	2.74	–0.95	3.72	–0.97
16.30	3.29	0.96	2.35	0.91	1.43	0.82	0.71	0.59	0.26	0.31	0.09	0.13	0.02	0.04	0.01	0.02
	0.03	–0.03	0.07	–0.08	0.15	–0.17	0.42	–0.39	0.95	–0.67	1.77	–0.86	2.69	–0.95	3.67	–0.97
16.35	3.34	0.96	2.39	0.91	1.47	0.82	0.74	0.61	0.28	0.33	0.10	0.14	0.02	0.04	0.01	0.02
	0.03	–0.03	0.07	–0.08	0.14	–0.16	0.40	–0.38	0.92	–0.66	1.73	–0.85	2.64	–0.95	3.62	–0.97
16.40	3.39	0.96	2.44	0.93	1.52	0.83	0.78	0.62	0.29	0.34	0.10	0.15	0.02	0.04	0.01	0.02
	0.03	–0.03	0.06	–0.07	0.13	–0.16	0.38	–0.37	0.88	–0.65	1.69	–0.84	2.60	–0.94	3.57	–0.97

TABLE 12–2—continued

	SEP		SEP		SEP		SEP		SEP		SEP		SEP		SEP	
	X =	13.00	X =	14.00	X =	15.00	X =	16.00	X =	17.00	X =	18.00	X =	19.00	X =	20.00
	I =	32.16	I =	28.61	I =	23.48	I =	21.80	I =	20.46	I =	21.61	I =	21.29	I =	24.16
	V =	0.004	V =	0.008	V =	0.014	V =	0.024	V =	0.026	V =	0.019	V =	0.010	V =	0.006
	T =	0.001	T =	0.002	T =	0.003	T =	0.004	T =	0.005	T =	0.004	T =	0.002	T =	0.001
16.45	3.43	0.96	2.48	0.92	1.56	0.84	0.81	0.63	0.31	0.35	0.11	0.16	0.03	0.05	0.01	0.02
	0.02	−0.03	0.06	−0.07	0.12	−0.15	0.36	−0.35	0.85	−0.63	1.64	−0.83	2.55	−0.94	3.52	−0.97
16.50	3.48	0.96	2.53	0.92	1.60	0.85	0.84	0.65	0.33	0.37	0.12	0.16	0.03	0.05	0.01	0.03
	0.02	−0.03	0.06	−0.07	0.12	−0.14	0.34	−0.34	0.82	−0.62	1.60	−0.82	2.50	−0.94	3.47	−0.96
16.55	3.53	0.96	2.57	0.93	1.64	0.85	0.87	0.66	0.35	0.38	0.13	0.17	0.03	0.06	0.02	0.03
	0.02	−0.03	0.05	−0.06	0.11	−0.13	0.33	−0.33	0.79	−0.61	1.56	−0.81	2.45	−0.93	3.43	−0.96
16.60	3.58	0.96	2.62	0.93	1.69	0.86	0.90	0.67	0.37	0.40	0.14	0.18	0.04	0.06	0.02	0.03
	0.02	−0.02	0.05	−0.06	0.10	−0.13	0.31	−0.32	0.76	−0.59	1.52	−0.81	2.41	−0.93	3.38	−0.96
16.65	3.63	0.97	2.67	0.93	1.73	0.87	0.94	0.68	0.39	0.41	0.15	0.19	0.04	0.06	0.02	0.03
	0.02	−0.02	0.05	−0.06	0.10	−0.12	0.30	−0.30	0.73	−0.58	1.48	−0.80	2.36	−0.92	3.33	−0.96
16.70	3.68	0.97	2.71	0.93	1.77	0.87	0.97	0.70	0.41	0.42	0.16	0.20	0.04	0.07	0.02	0.03
	0.02	−0.02	0.05	−0.05	0.09	−0.11	0.28	−0.29	0.70	−0.56	1.44	−0.79	2.32	−0.92	3.28	−0.95
16.75	3.72	0.97	2.76	0.94	1.82	0.88	1.01	0.71	0.43	0.44	0.17.	0.21	0.05	0.07	0.02	0.04
	0.02	−0.02	0.04	−0.05	0.09	−0.11	0.27	−0.28	0.68	−0.55	1.40	−0.78	2.27	−0.91	3.24	−0.95
16.80	3.77	0.97	2.81	0.94	1.86	0.89	1.04	0.72	0.45	0.45	0.18	0.22	0.05	0.08	0.02	0.04
	0.02	−0.02	0.04	−0.05	0.08	−0.10	0.25	−0.27	0.65	−0.54	1.36	−0.77	2.22	−0.91	3.19	−0.95
16.85	3.82	0.97	2.86	0.94	1.90	0.89	1.08	0.73	0.47	0.47	0.19	0.23	0.05	0.08	0.03	0.04
	0.01	−0.02	0.04	−0.05	0.08	−0.10	0.24	−0.26	0.62	−0.52	1.33	−0.76	2.18	−0.90	3.14	−0.95
16.90	3.87	0.97	2.90	0.95	1.95	0.90	1.12	0.74	0.50	0.48	0.20	0.24	0.06	0.09	0.03	0.04
	0.01	−0.02	0.04	−0.04	0.07	−0.09	0.23	−0.25	0.60	−0.51	1.29	−0.75	2.13	−0.90	3.09	−0.94
16.95	3.92	0.97	2.95	0.95	1.99	0.90	1.15	0.75	0.52	0.50	0.21	0.25	0.06	0.10	0.03	0.05
	0.01	−0.02	0.03	−0.04	0.07	−0.09	0.21	−0.24	0.57	−0.49	1.25	−0.74	2.09	−0.89	3.05	−0.94

volatility are based on the previous day's settlement prices for puts, calls and the future. More specifically, since out-of-the-money puts and out-of-the-money calls are most actively traded, the implied volatility numbers are derived from these options. Thus, the implied volatilities for the 16 strike and below are based on put prices, while for the 17 strike and above implied volatilities are based on call prices. Although put-call parity should make the volatilities the same for any particular strike, no matter whether the put or call price is used in the calculation, sometimes settlement prices do not reflect put-call parity. In those cases the procedure just described resolves the issue.

The most interesting characteristic of the implied volatilities in Table 12–2 is that the volatilities differ across strike prices. In particular, for the three strikes below the current futures price of 16.65, the implied volatilities rise from 21.80 (at the 16 strike) to 28.61 (at the 14 strike). On the other hand, the implied volatilities for the three strike prices above 16.65 are all about the same (21 percent). The observed pattern stems from the way we calculated implied volatility—a numerical solution of the Black [1976] option pricing formula based on the settlement price of each option. From the marketmaker's perspective, as long as the structure of implied volatilities across strike prices is stable from day to day, it makes sense to use that pattern as a guideline for quoting bids and offers. In point of fact, the skewed structure of volatilities across different strikes shown in Table 12–2 has been present with brief exceptions, since the inception of crude oil options trading in 1986. Thus, marketmakers can and do rely upon fair value numbers that reflect different volatilities for different strike prices in crude oil options (as well as for other kinds of options.)

From a conceptual perspective, we should try to understand what this observed pattern for implied volatilities really means. After all, there is only one actual volatility for the underlying asset. Moreover, using historical volatility as an input to the option pricing formula, described above as an alternative to the implied volatility approach, would obviously produce only a single number for volatility. What then does the structure of volatility across different strike price reflect? To some extent, the resolution of this question requires a theoretical discussion that goes beyond our scope. Nevertheless, a brief overview might prove helpful.

The volatility component of Black [1976], as well as the original Black-Scholes [1973] option pricing model, reflects the simplifying assumption that asset prices follow a smooth, continuous, evolution over time (called a *diffusion process*). In particular, no discontinuous price jumps (either up or down) are allowed for. Real world prices, however, do sometimes exhibit discontinuous price movements. Moreover, such sharp price jumps are especially beneficial to buyers of out-of-the-money options, and especially detrimental to sellers of out-of-the-money options. For example, the buyer of a September put with a 15 strike price would benefit considerably if there were an overnight $2.00 collapse in oil prices, so that the relatively cheap deep out-of-the-money puts suddenly became very valuable in-the-money puts. Sellers of such puts are especially vulnerable under such circumstances for two reasons: (1) there is no chance to rebalance the hedge between yesterday's close and today's opening; (2) the deltas on such out-of-the-money options change dramatically with precipitous price movements (in our example from about minus .1 to over minus .5).

The explanation for why deep out-of-the-money puts have relatively high implied volatilities is now fairly straightforward. Enthusiastic buyers and reluctant sellers push up the market clearing price for the option above the level suggested as the fair value based on a simple diffusion process for price movements in the underlying asset. When this price is fed into the Black [1976] options pricing formula along with the four other predetermined option characteristics (strike, futures price, expiration and interest rate), the model produces a high value for the residual unknown factor—labelled *implied volatility*.

Although this explanation seems reasonable, it leaves open the question of why the out-of-the-money call options in Table 12–2 do not reflect a similar pattern. In other commodity options, such as gold, both out-of-the-money puts and out-of-the-money calls have higher implied volatilities than the at-the-money options. The answer in the case of crude oil options rests with the market's assessment of the probability of price jumps. Since the Organization of Petroleum Exporting Countries (OPEC) is a major force in the oil market, and since the potential collapse of this cartel in recent years has been a greater threat than the likelihood of stricter control over oil supplies, the probability of a sharp collapse in oil prices is much greater than the probability of a sharp increase. Thus, out-of-the-money put prices are bid up while out-of-the-money call prices reflect the normal probabilities associated with a smooth evolution in the price of the underlying asset. This discussion indicates that, in practice, the implied volatility parameter for a given option reflects things other than just a trader's forecast of price volatility, including estimates of the size and direction of price jumps, risk aversion and so on.

Some marketmakers have taken advantage of option pricing models such as Merton [1976] that explicitly take account of potential jumps in the price of the underlying. By and large, these more sophisticated models require information, such as the frequency of potential jumps, that the marketmaker can only guess at. Since marketmakers utilize these models primarily as guidelines for centering quoted bids and offers (as well as for managing options positions), the added sophistication of an options pricing model with a jump process is probably not worth the effort.

The most vexing problem confronting options marketmakers is that volatility, however measured, has a large amount of uncertainty associated with it. Recall that volatility is supposed to measure the standard deviation of the percentage price change of the underlying asset during the life of the option. From this perspective, it is possible that either true volatility or expected volatility can change over time, implying a change in the fair value of the options. True volatility can change for fundamental reasons, such as in the case of crude oil options, the announcement of an OPEC meeting, or in the case of Treasury bond options, the announcement of a change in Federal Reserve operating techniques. Expected volatility moves up and down as market participants reassess their subjective view of the economic environment, and the prospects for price volatility in the asset underlying their particular option.

Marketmakers are affected in two ways by fluctuations in volatility over time and the associated change in the fair values of options. First, the marketmaker must change quoted bids and offers. Second, the value of the marketmaker's portfolio of options changes as well. As far as bid-ask quotes are concerned, marketmakers using implied volatility as input to the fair value calculation automatically revise their estimate of volatility every day. Other marketmakers will adjust their bids and offers to order flow in the marketplace. On the other hand, the impact of a change in volatility on an option's value (called kappa or vega), and the effect on the value of the marketmaker's portfolio, is a more serious problem. In fact, this "kappa risk," along with theta and gamma, is something that marketmakers take into account when deciding how to balance their options portfolio.

To provide an idea of the magnitudes involved, look at the top of each column in Table 12–2 where the value for V gives the impact of a one percentage point change in volatility on the value of the option (at yesterday's settlement price). In the September 17 column, $V = .026$, suggesting that the value of the 17 call (which was .39) would fall to .364 if volatility declined one percentage point (to 19.46) or would rise to .416 if volatility increased by one percentage point (to 21.46). A marketmaker who is long ten September 17 calls (and short futures to be delta-neutral) could gain or lose more than $200 simply because the market's estimate of volatility changed by one percentage point. Since such changes in volatility are quite frequent, marketmakers have still another reason to prefer a balance of long and short options in their portfolios. In this way the "kappa risk" of being long the 17 calls, for example, would be partially offset by being short the 18 calls.

The end of the story is that marketmakers would like to earn the bid-asked spread and manage their options positions to be delta, gamma, theta and kappa neutral. Since this is a difficult if not impossible task, market-making in options turns out to be a complicated business. Marketmakers apply intuition, order flow, fancy models and anything else that helps them to understand and manage options positions.

12.7 CONCLUSIONS FOR PUBLIC TRADERS

This overview has provided some insight into the decision rules and guidelines followed by options marketmakers quoting bids and offers in the marketplace. Unless one is thinking about becoming a marketmaker, much of the detail is probably of academic interest. There are some lessons, however, that can be drawn from our descriptions that might be useful for public traders who utilize the liquidity services of marketmaking dealers in options.

Perhaps the most important outcome of our overview is that the liquidity costs implied by bid and offer quotes are not written in stone. They are negotiating points from which a marketmaker will sometimes depart, depending upon his or her inventory position. Thus, public traders should always inquire about the bid and offer and then instruct the broker who will execute the order to improve on the marketmaker's bid when buying (by entering a higher bid) and improve on the marketmaker's offer when selling (by entering a lower offer). The trader's improved bid or offer might just uncover an anxious seller or buyer, allowing the trader to buy or sell at better prices than the quoted bid or offer. The broker should be instructed, however, to lift offers or hit bids in the event that the broker's market is not acted upon within a short time period. Thus, liquidity costs might be reduced, without necessarily sacrificing the liquidity services of the marketmaker, if proper instructions are given to a broker.

A public trader should not waste time trying to uncover nearly riskless arbitrage trades. They exist, for relatively brief time periods (seconds in a futures option pit), and immediately find their way into a marketmaker's position. Public traders do not have the time, the low transactions costs, or the execution facilities to compete with marketmakers in this area.

A trader should avoid placing orders during the opening of trading. Marketmakers have relatively poor information about where the true equilibrium quote should be at that time. This translates into a wider bid-asked spread, hence larger transactions costs for the trader. Unless there are overriding considerations, avoid trading during the opening few minutes.

Public traders who deal with OTC marketmakers must be especially careful to search for the best bid or offer. Without centralized order flow there is no guarantee that the highest bid and lowest offer have been uncovered. Moreover, the larger the volume the trader wants to buy or sell, the more dealers he or she should contact. The dollar saving varies directly with the size of the transaction. It pays to incur search costs (a bid or offer may even "expire" in the process) if a large trade must be completed.

Finally, and perhaps most importantly, as a general rule, use the marketmakers' liquidity services by hitting bids and lifting offers. Do not attempt to play marketmaker by monitoring order flow and trying to beat a marketmaker to a bid or offer that is represented in the marketplace by some other public trader. Marketmakers will prevail in such contests nine times out of ten. The cost of chasing a market up and down as marketmakers' bids and offers are revised continuously will usually be substantially more expensive than the bid-asked spread. Public traders should surely try to execute at better prices, as pointed out above. But once a broker has exercised due diligence in that regard, the best advice is to hit bids and lift offers; paying the liquidity costs is usually the least expensive component of a speculative transaction.

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