Vertical Spread Design

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Abstract

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Based on data on options on Eurodollar futures, the design and trading of vertical spreads (a.k.a. bull and bear spreads) are examined. Reducing the cost and/or increasing the profit likelihood of long positions appears more important than risk reduction on short positions in most traders' decisions to employ vertical spreads instead of single options. We find little evidence that vertical spreads are designed so as to minimize vega risk, maximize absolute deltas, or engineer positive gammas or negative thetas. There is also no evidence that the shape of the smile impacts spread design. The strong preference for out-or-the-money strikes on debit spreads is consistent with the hypothesis that debit spread traders seek either moderately low prices and/or high values of delta per dollar at risk but reasons for the slight preference for out-of-the-money strikes on credit spreads are unclear. We find that when futures are combined with a vertical spread position, it is almost always in a ratio which reduces the position's net delta to zero turning the spread into a volatility trade. Seagulls, in which a third option adds a tail to the vertical spread in the same direction, represent a fairly actively traded but rarely discussed variant of the standard vertical spread design with lower prices and higher deltas than bull and bear spreads.

Vertical Spread Design

Vertical spreads (a.k.a. bull and bear spreads) are a popular options trading strategy. For instance, in the Eurodollar futures options market, they represent about 9.4% of all option trades of 100 contracts or greater and account for about 11.6% of the trading volume (Chaput and Ederington, 2003). Reflecting this popularity, basic characteristics of vertical spreads are discussed in every derivatives text and in the practitioner literature, e.g, McMillan (1980) , yet to our knowledge, no researcher has examined their design and trading in any depth. No one has asked how vertical spreads should be designed theoretically and no one has examined how they are structured in practice. We seek to fill this void by examining the design and trading of vertical spreads and their closely related cousins, seagulls (in which a third option adds a tail to the vertical spread in the same direction) in the Eurodollar futures options market.

The basic mechanics of vertical spreads are well known. For instance, a bull call spread is created by buying a call option at one strike, X_1, and selling a call with the same expiry at a higher strike, X_2. The profits to this strategy, when held to expiration, as a function of the underlying asset price are illustrated in Exhibit 1a where the profits on the two individual options are shown as dotted lines and the spread as the solid line. As compared with simply buying call option X_1, the bull spread buyer gives up the additional profits if the underlying asset price rises beyond X_2 . However, she also lowers the cost of the spread and therefore her losses if the underlying asset price does not rise as anticipated. As illustrated in Exhibit 1b, an equivalent bull spread can also be created by buying a put with strike X_1 and selling a put with the higher strike X_2. As compared with simply shorting the put at the higher strike, the put spread trader lowers the net price received but limits her losses if the underlying asset price declines.

Based on trades of vertical spreads for Eurodollar futures options, this paper examines how vertical spreads are designed and what those designs tell us about the objectives of vertical spread traders. Comparing vertical spreads with simple call and put positions, we first ask whether most vertical spread traders choose vertical spreads in order to reduce their risk and/or margin requirements on short positions or to reduce the net cost and raise the likelihood of gain on long positions. Somewhat surprisingly, we find the latter objective dominates. We then turn to questions of vertical spread design. Having settled on a bullish or bearish spread and an expiry, a vertical spread trader must decide whether to construct the spread using calls or puts and what strike pair to utilize. We explore these design choices and what they reveal about traders' objectives. We first analyze the implications of these decisions for attributes of the spread, such as cost, the profit pattern, and spread Greeks. Then we explore how most bull and bear spreads are constructed on the Eurodollar options market.

We find that many of the advantages of vertical spreads hyped in the practitioner literature appear unimportant to the majority of vertical spread traders. Specifically, we find little evidence that most vertical spread traders design their vertical spreads to: 1) maximize delta, 2) minimize vega risk, 3) create spreads with positive gamma, 4) create spreads with negative theta, or 5) exploit the smile by selling options with high implied volatilities and buying those with low implied volatilities. There is evidence that on debit spreads vertical spread traders chose strikes which result in relatively high deltas per dollar invested. This objective is also consistent with the observed tendency to choose small differentials between the two strikes.

In addition to straight bull and bear spreads we consider two common variations. First, vertical spread trades are sometimes accompanied by a simultaneous futures trade. We explore the reasons for this and how the addition of the futures to the trade alters the trader's position. Second, we analyze positions, that are sometimes termed "seagulls," in which a third option adds a tail to the vertical spread in the same bull or bear direction. While rarely discussed in derivative texts, seagulls are reasonably common in the Eurodollar options market. As compared with the underlying vertical spread, we find that seagulls have higher deltas, lower prices and usually have opposite signs for gamma, vega, and theta.

The paper is organized as follows. In the next section we describe our data and document basic characteristics of bull and bear trades in the Eurodollar futures options market.

In section II, we look at traders' choices of debit or credit spreads and what this reveals about why traders employ verticals. In sections III, IV, and V respectively, we analyze the trader's three design choices: (1) calls or puts, (2) the relation of the two strike prices the underlying asset price F, and (3) the gap or differential between the two strikes. Combinations of vertical spreads with futures are considered in section VI and seagulls in section VII. Section VIII concludes the paper.

I. Basic Characteristics

The Data

As explained in Chaput and Ederington (2003), existing public option data sets do not identify spread and combination trades. However, data on large option trades in the Chicago Mercantile Exchange's market for Options on Eurodollar Futures (the world's most heavily traded short-term interest rate options market) with these identifiers was generously provided to us by Bear Brokerage.[1] Bear Brokerage regularly stations an observer at the periphery of the Eurodollar pits with instructions to record all option trades of 100 contracts or more. For each large trade, this observer records (1) the net price, (2) the clearing member initiating the trade, (3) the trade type, e.g., naked call, straddle, vertical spread, etc., (4) a buy/sell indicator, (5) the strike price and expiration month of each leg of the trade, and (6) the number of contracts for each leg. If a futures trade is part of the order, he also records the expiration month, number, and price of the futures contracts. Since in spread trades buyer and seller normally agree on a net price, not separate prices for each leg of the spread, only this price is recorded.[2] The trades recorded by Bear Brokerage account for approximately 65.8% of the options traded on the observed days - the remainder being unrecorded smaller trades.

We only observe vertical spreads which are ordered as such. If an off-the-floor trader places one order to buy 200 calls at one strike and another to sell 200 calls at another strike with the same expiry, our records show two naked trades, not a vertical spread. Consequently, our data may understate the full extent of vertical spread trading. However, if a trader splits his order, he cannot control execution risk. For example, if he orders 200 bull spreads, he can set a net price limit of 10 basis points, which he cannot do if he splits the order. If he sets limits on each leg, one leg may wind up being executed without the other. Consequently, the traders to whom we have spoken think the data capture almost all spread trades.

Bear Brokerage provided us with data for large orders on 385 of 459 trading days during three periods: (1) May 12, 1994 through May 18, 1995, (2) April 19 through September 21, 1999 and (3) March 17 through July 31, 2000.[3] Data for the other 74 days during these periods was either not collected due to vacations, illness, or reassignment or the records were not kept. As described in Chaput and Ederington (2003), we applied several screens to the raw data removing trades solely between floor traders (since it is unclear who initiated the trade), obvious recording errors, and incomplete observations. The resulting data set consists of 13,597 large trades on 385 days of which 1276 or 9.4% were vertical spreads. Data on daily option and futures prices were obtained from the Futures Industry Institute.

Trade Characteristics

Bull spreads slightly exceed bear spreads in our sample - 53.2% to 46.8%. Unfortunately, the terms “bull” and “bear” can be confusing in the Eurodollar market as can “call” and “put”. As explained by Kolb (2003), and Hull (2003), although Eurodollar futures and options are officially quoted as 100-LIBOR, in valuing these options traders generally use pricing models defined in terms of LIBOR, not 100-LIBOR.[4] Here we treat the options as options on LIBOR. So by “bull spread” we mean a spread that is betting on, or hedging against, an increase in the interest rate.

In interpreting these percentages, note that in our data we cannot distinguish between trades which open and close a position. If every position were closed with an offsetting trade, we would observe a 50-50 ratio of bull spreads to bear spreads regardless of whether most initial trades were bulls or bears. The ratio only differs from 50-50 to the extent some positions are held to expiration.[5] This suggests that for opening positions, the proportion of bull spreads in the sample is somewhat greater than 53.2%. Consistent with this, over the last two weeks before expiration, when one would expect many position closing trades, bear spread trades exceed bulls (59% to 41%).

Basic characteristics of the vertical spreads in our sample are reported in Exhibit 2. The median size trade in our sample is fairly large - 500 contracts per leg or a total of 1000 contracts. Of course this is conditional on the fact that the minimum size is 100 contracts per leg or 200 total. At 3.8 and 2.9 months respectively, the mean and median times to expiration are roughly in line with those observed on naked call or put trades and considerably shorter than those observed on most volatility spreads such as straddles. The average differential or gap between the two strikes in a vertical spread is 31.2 basis points and the median is 25. The smallest possible gap is 25 basis points on all spreads except those based on close-to-the-money options expiring in 3 months or less observed after May 1995. Hence, the strike gap on most vertical spreads is at or close to the minimum.

As seen in Exhibit 2, the median net price is 7.5 basis points (bp). Since the nominal size on a Eurodollar contract is $1 million, each basis point represents $25 so 7.5 bp translates into a dollar price of $187.50. On a debit spread (net initial cash outflow), a price of 7.5 bp on a spread with a 25 bp strike differential means that the maximum loss (if held to expiration) is 7.5 bp and the maximum profit is 17.5 bp. On a credit spread, the maximum profit would be 7.5 bp and the maximum loss 17.5 bp.

II. Why Verticals?

Our first question is why traders use vertical spreads instead of positions in a single call or put to speculate on future changes in the underlying asset price. Consider speculative positions using single options. A trader wishing to speculate on a increase in the LIBOR rate could either buy a call or write a put. If she buys a call, she faces unlimited gains and bounded losses; if she shorts a put, her possible gains are bounded while her possible losses are unbounded. Looking at the first possibility, the long call position, suppose she decides to convert this into a call bull spread by shorting a second call at a higher strike. By converting the call to a call bull spread, the trader lowers her net cost (and therefore her maximum possible loss) and lowers the breakeven point (thereby raising the profit likelihood) but bounds her profits if the underlying asset price rises sharply. Turning to the second possibility, suppose the trader starts with a written put and converts this into a put bull spread by buying a second put at a lower strike. In this case, the trader reduces her risk exposure since possible losses (at expiration) are now limited to the difference in the two strike prices less the net price. Since possible losses are now bounded, she also lowers her margin requirement. The disadvantage of converting the naked put write to a bull spread is that she lowers her maximum gain and raises the breakeven point (and therefore the likelihood of a loss) .

For the same strikes, both call and put bull spreads have identical deltas, vegas, and gammas, and payoff patterns but the net cash flow differs. In the put case, the resulting vertical spread is a credit spread (initial cash inflow) since the price of the bought option is lower than that of the sold option. However, the call bull spread is a debit spread since the price of the bought option exceeds that of the sold option. The same holds true for bear spreads leading to the proposition:

***Proposition 1**: If vertical spread traders are employing vertical spreads in order to reduce possible losses on short positions, the resulting vertical spreads will be credit spreads. If using vertical spreads to reduce the cost and increase the profit likelihood on long positions, the resulting verticals will be debit spreads.*

In our sample of 1276 vertical spreads, debit spreads outnumber credit spreads 60.8% to 39.2% - a ratio which is significantly different from 50-50 at the .0001 level. Again note that if all positions were closed with an offsetting trade, this ratio would be 50-50 suggesting that proportion of debit trades for position opening trades exceeds 60.8%. Consistent with this, credit spread trades represent a slight majority over the last two weeks before expiration when one would expect a higher proportion of position closing trades. This implies that significantly more traders are using vertical spreads to reduce their cost and/or increase the profit likelihood than are using them to limit losses and/or reduce margin requirements. This came as something of a surprise since risk reduction is an oft-cited and intuitively appealing use of vertical spreads.

III. Vertical Spread Design - Calls or Puts? - Debit or Credit?

The vertical spread trader faces three design choices: (1) whether to use calls or puts, (2) the relationship of the strikes to the underlying asset price, and (3) the size of the gap between the two strikes. We consider each in turn starting with the question of calls or puts. When the extension to bear spreads is trivial, we only analyze bull spreads. Because of its tractability and wide usage by Eurodollar traders,[6] we first analyze positions using Black's options on futures model (1976). Because Eurodollar options are American, we also employ the American options model of Barone-Adesi and Whaley (1987) (hereafter BAW) for most empirical comparisons.

Calls versus Puts - Analysis

If put-call parity holds and option prices conform to the Black model, then for the same strikes, it makes little difference on most dimensions whether the spread is constructed using calls or puts. To begin with, delta, gamma, and vega are identical according to the Black model. Let X_1 be the lower strike and X_2 the higher. The Black delta for a call at strike X_1 is $e^{-rt}N(d_1)$ where $d_1 = [\ln(F/X_1) + .5\sigma^2 t]/\sigma\sqrt{t}$, F is the underlying asset price, σ the volatility, t the time to expiration and N() is the cumulative normal distribution. Assuming the volatilities, σ, are the same, as put-call parity implies, the delta for the put at the same strike is $e^{-rt}[N(d_1)-1]$. Hence the delta for both call and put bull spreads at strikes X_1 and X_2 is $e^{-rt}[N(d_1)-N(d_2)]$ where $d_2 = [\ln(F/X_2) + .5\sigma^2 t]/\sigma\sqrt{t}$. Note that in our terminology d_1 and d_2, represent the same expression at strikes 1 and 2, i.e., not the usual relation where $d_2=d_1-\sigma\sqrt{t}$. Since gamma and vega are identical for puts and calls at the same strike, they are also identical for put and call verticals.

Assuming put-call parity, the present value of possible profits at expiration is also identical for call and put verticals. If the price of a call at strike X_1 (X_2) is C_1 (C_2), then the net cost of a vertical constructed using calls is C_1-C_2. If the final futures price $F_T<=X_1$, neither call finishes in the money and the profits of the vertical are $-(C_1-C_2)$. If $F_T>=X_2$, profits in present value terms are $[(X_2-X_1)e^{-rt} -(C_1-C_2)]$ and if $X_1<F_T<X_2$, profits are $[(F_T-X_1)e^{-rt} -(C_1-C_2)]$. Consider now a vertical constructed using puts at the same strikes. If $F_T<=X_1$, both puts finish in the money so discounted profits are $[-(X_2-X_1)e^{-rt} + (P_2-P_1)]$ where P_1 and P_2 indicate put prices at strikes X_1 and X_2 respectively. However, according to put-call parity $P_1=C_1-F+X_1e^{-rt}$ and similarly for P_2. Hence $P_2-P_1 = -(C_1-C_2)+(X_2-X_1)e^{-rt}$ so profits on the put vertical if $F_T<=X_1$ are identical to those on the call vertical, i.e., $-(C_1-C_2)$. Similarly if $F_T>=X_2$, profits for both call and put verticals are $P_2-P_1 = -(C_1-C_2)+(X_2-X_1)e^{-rt}$ and if $X_1<F_T<X_2$, profits are $[(F_T-X_1)e^{-rt} -(C_1-C_2)]$.

While present values are identical for call and put verticals at the same strikes, their cash flow patterns differ. Call bull spread and put bear spreads are debit spreads, i.e., there is a net cash outflow at the initiation of the spread. Put bull spreads and call bear spreads are credit spreads.[7] We see three possible reasons this cash flow pattern could be important to traders: (1) discount rate differences, (2) margin requirements, and (3) early exercise.[8] Considering discount rates, if the trader's cost of capital is higher than the interest rate underlying the option prices, she might prefer a positive initial cash flow - a credit spread. If her cost of capital is lower, a debit spread might be preferred. If margin requirements impose a significant cost, debit positions should be preferred since they do not require margins.

Avoidance of early exercise implies a preference for debit spreads - particularly for put spreads. In a debit spread, the vertical trader holds a long position in the option for which early exercise is first optimal so always maintains control of his position. For instance, in a call bull spread, the vertical trader has a long position in the lower strike option. In contrast, in a put bull spread, the higher strike option, the one shorted, is the one for which exercise will be optimal first. If this option is exercised early, then the bull spread position suddenly becomes a bear position since the trader still holds the long put. If avoidance of early exercise is important, debit spreads should be preferred and this preference should be stronger for put spreads since they are more likely to be exercised early. Thus, our second proposition is :

Proposition 2: *Avoidance of margin requirements and early exercise on the short option implies a preference for debit spreads and that vertical spread traders should particularly avoid put credit spreads.*

Results

We have already noted that 60.8% of vertical spread trades in our sample are debit spreads. According to Proposition 2, this preference should be stronger for bull spreads than for bear spreads since bull credit spreads are put spreads. In the case of bull spreads, 69.3% use calls (debit spreads) and 30.7% use puts (credit spreads), a difference which is significant at the .0001 level. In the case of bear spreads, 48.8% employ calls (credit spreads) and 51.2% puts (debit spreads), a difference which is significant at the .05 level but not at the .01 level. Consistent with Proposition 2, the difference between these two proportions is significant at the .0001 level.

IV. Vertical Spread Design - Strike Price Levels

The vertical spread trader must also decide which strike prices to utilize. We view this as a choice of (1) the gap or differential between the two strikes, and (2) the relation of the two strikes to the underlying asset price. This section explores the latter question considering the consequences of this choice for such spread characteristics as price, return skewness, early exercise likelihoods, and spread Greeks assuming a constant strike differential. To simplify the analysis, we initially assume equal volatilities at all strikes - an assumption relaxed later.

Spread price and return skewness

In the practitioner literature one of the most cited advantages of a vertical spread over a long position in a single call or put is that the cost of the position is reduced by shorting a second option. Obviously, this argument only applies to debit spreads for which it implies a preference for out-of-the-money (OTM) strikes. Let the two exercise prices in a call bull spread be X_2 and X_1 where $X_2>X_1$. According to Black's model for options on futures, the derivative of the call price with respect to the strike is $-e^{-rt}N(d^*)$ where $d=[\ln(F/X)+.5\sigma^2 t] / \sigma\sqrt{t}$ and $d^*=d-\sigma\sqrt{t}$.. Hence the impact of an equal increase in both strikes on the price of a bull call spread is $-e^{-rt}[N(d_1^*)-N(d_2^*)]$ where again the subscripts 1 and 2 denote d* at the different strikes. Since $X_2>X_1$, $N(d_1^*)>N(d_2^*)$, and an equal increase in both strikes lowers the net price as illustrated in Exhibit 3. In summary,

Proposition 3: *Cost minimization implies a preference for OTM strikes on debit spreads.*

While intuitively appealing, the cost minimization argument ignores two obvious facts: (1) raising the two strike prices also reduces the likelihood that the position will finish in-the-money (ITM) and payoff at maturity, and (2) the vertical spread trader can reduce her cost to zero by choosing a credit rather than a debit spread. Taking these factors into account, another way of stating this preference - and one that applies to credit spreads as well - is a preference for positively skewed returns. Since the price of a debit spread represents the maximum possible loss and the price of a credit spread represents the maximum possible profit, it follows that for bull spreads (whether calls or puts), choosing a higher strike price pair with the same differential reduces the maximum loss and increases the maximum profit. However, higher strikes also raise the breakeven point so lowers the likelihood that a profit will be realized leading to:

Proposition 4: *A preference for positive skewness, i.e., small high probability losses and large lower probability gains, implies that vertical spread traders should choose OTM strikes for debit spreads and ITM strikes for credit spreads.*

Obviously, if traders prefer negative skewness, the implications are reversed. While propositions 3 and 4 focus on traders who intend to hold to expiration, attention is now turned to traders with shorter horizons.

Spread Delta

Since the presumed goal of vertical spread traders is speculation on changes in the underlying asset price, maximizing the spread's absolute delta seems a logical objective.[9] The Black delta for a call bull spread is $e^{-rt}[N(d_1)-N(d_2)]$ where again $d_1 = [\ln(F/X_1) + .5\sigma^2 t]/\sigma\sqrt{t}$, $d_2 = [\ln(F/X_2) + .5\sigma^2 t]/\sigma\sqrt{t}$ and X_1 and X_2 are the two strikes with $X_2>X_1$. Delta's derivative with respect to X_1 is $-[(e^{-rt}/\sigma\sqrt{t})\ (n(d_1)/X_1)]$ while that with respect to X_2 is $[(e^{-rt}/\sigma\sqrt{t})\ (n(d_2)/X_2)]$ so for an equal increase in both strikes, the derivative is $(e^{-rt}/\sigma\sqrt{t})[(n(d_2)/X_2)-(n(d_1)/X_1)]$. By setting this expression equal to zero, we obtain that the Black delta is maximized when $n(d_2)/n(d_1) = X_2/X_1$. For the strikes in our sample, X_2/X_1 is generally greater than but close to 1.0 so the delta maximizing strike pair is normally one where $X_2>F>X_1$ and their mean is less than but close to F. For instance in our sample, approximate medians are: t=.25 (3 months), σ=.15, and r=F=6.00%. For a strike gap of 25 basis points and these values, delta is maximized when the mean strike is 5.984%, i.e. just below the underlying futures price of 6.0%. The BAW model gives virtually identical results, specifically delta is maximized where the mean strike is 5.978%. Delta is graphed as a function of the mean strike in Exhibit 3 where the parameters are set equal to the approximate medians in our sample.

In the Eurodollar options market, the traded strikes are in increments of 25 or (more rarely) 12.5 basis points,[10] so it is normally impossible to choose strikes where $n(d_2)/n(d_1)$ is exactly equal to X_2/X_1. Among the strikes actually traded, the strike pair which maximizes delta is virtually always the pair with $X_2>F>X_1$ whose mean is closest to F. For the minimum strike price gap (most of our verticals sample), this is the at-the-money (ATM) strike pair so we will use this term although in the few cases when the gap between the strikes is large, the strikes may be some distance from F.

Proposition 5*: Delta maximizing vertical spread traders should choose ATM strikes.*

Alternatively, debit spread traders might seek to maximize delta per $1 invested rather than delta per contract.[11] For a fixed strike gap, as the mean strike is raised, the net price of call debit verticals falls and that of put debit verticals rises. Since the net price changes faster than the spread's delta, debit vertical spread traders maximize delta per dollar invested by choosing out-of-the-money (OTM) strikes. This is illustrated for debit call spreads for approximate median values in our sample in Exhibit 4. As shown there, maximizing delta per dollar would imply choosing options as far OTM as possible though this would entail ever greater vega risk. Note that the objective of maximizing delta per dollar invested applies only to debit spreads since the trader's net investment on credit spreads is negative. Hence, our sixth proposition is:

Proposition 6: *Debit spread traders seeking to maximize delta per dollar invested should choose OTM strikes.*

Vega

The supposed raison d'etre for spreads and combinations is that they allow traders to construct positions which are highly sensitive to some risk factors and insensitive to others. In a separate paper on volatility spreads, e.g., straddles and strangles, (Chaput and Ederington, 2005), we find evidence that straddles and strangles are designed so that their deltas are near zero and vegas and gammas are high. Analogously, we expect vertical spread traders to prefer spreads with high deltas and low exposure to vega risk.

In the Black model, vega = $[Fe^{-rt}\sqrt{t}]\, n(d)$ for both calls and puts where n() is the normal density and the other variables are as defined above. Consequently, a vertical spread's vega (also its gamma) is zero according to the Black model when $n(d_1)=n(d_2)$ where again $d_1=[\ln(F/X_1)+.5\sigma^2 t]/\sigma\sqrt{t}$ and $d_2=[\ln(F/X_2)+.5\sigma^2 t]/\sigma\sqrt{t}$. Since the standard normal density is symmetric around zero, this occurs when d_2=-d_1 or $\ln(F/X_1)+\ln(F/X_2)=-\sigma^2 t$ which occurs when the geometric average of the two strikes $(X_1X_2)^{.5}=Fe^{.5\sigma^2 t}$. For the values of σ and t in our sample, the exponential term is normally close to 1.0 so vega is zero when the geometric mean of the two strikes is just slightly above F. For example in our sample, the median time to expiry is approximately 3 months or t = .25 and the median implied volatility σ = .15 so $e^{.5\sigma^2 t}$=1.0028. For F=6.00%, vega is maximized when the geometric mean of the two strike is 6.017%. In Exhibit 3, we graph the bull spread Black vega as a function of the mean strike when σ, t, r, and F take their approximate median values and the strike price differential is 25 basis points. The implications of the BAW model are virtually identical. For instance for the same example parameters, the BAW vega is zero when the (geometric) mean strike is 6.006%.

Because the traded strikes are in increments of 25 or 12.5 basis points, traders cannot normally find strikes where $(X_1X_2)^{.5}$ is exactly equal to $Fe^{.5\sigma^2 t}$. In this case the vega minimizing pair is virtually always that whose geometric mean is closest to F. As in the delta analysis above, we term these ATM strikes although in the few instances when the strike gap is large, they may be some distance on either side of F.

Proposition 7: *Vertical spread traders seeking to minimize their exposure to vega risk should choose ATM strikes, i.e., strikes which straddle the underlying asset price and whose mean is closest to F.*

As illustrated in Exhibit 3, vega is also close to zero for far ITM and OTM options. However, their deltas are also minuscule and such strikes choices are almost non-existent in our sample. As illustrated in Exhibit 4, choosing OTM strikes to maximize delta/price in debit spreads also leads to high values of vega/price.

Gamma

All other things equal, traders should prefer spread positions with positive gammas so that they profit more if the underlying asset price moves in the expected direction than they lose if it moves an equal distance in the opposite position. Like vega, an option's gamma is proportional to n(d), hence a vertical spread's gamma is zero when the geometric mean strike $=Fe^{.5\sigma^2 t}$. A positive gamma is achieved by longing the strike closest to $Fe^{.5\sigma^2 t}$ and shorting the option further away which leading the proposition:

Proposition 8: *Vertical spread traders seeking positive gammas should choose out-of-the-money (OTM) strikes for debit spreads and in-the-money (ITM) strikes for credit spreads.*

A goal of maximizing gamma per dollar invested would lead to an even stronger preference for OTM strikes on debit spreads.

Theta

According to writers such as Natenberg (1994), one advantage of vertical spreads versus naked call or put positions is that the spread can be constructed so that theta is small or even has a sign opposite to that of a naked option position with the same delta.[12] If one longs a naked call betting on an increase in the underlying asset price and instead the price of the underlying asset remains unchanged, then over time the option's value declines and the position loses money. Suppose instead that one constructs a bull call spread where both strikes are ITM. Initially the price of the spread is less than the strike price gap X_2-X_1, but as expiration approaches with the underlying asset price unchanged, the value of the spread approaches X_2-X_1 so the bull trader benefits.

As analyzed more fully in Chaput and Ederington (2005), for a given expiry, an option's theta is roughly proportional to n(d) as defined above.[13] Consequently, debit spreads with ITM strikes generally have negative thetas (so that the value of the spread increases as expiration approaches), debit spreads with OTM strikes have positive thetas, and debit spreads with ATM strikes have small absolute thetas. For credit spreads, the relation is reversed. In summary:

Proposition 9: *Vertical spread traders seeking negative thetas should choose ITM options for debit spread positions and OTM options for credit spreads.*

Since this is the opposite of the requirement for a positive gamma, the spread trader normally faces a tradeoff between these two desirable traits.

Liquidity and Early Exercise

As discussed above, vertical spread traders can avoid situations in which the sold option is the first on which exercise is optimal by choosing debit spreads. They can further insure against early exercise of the sold option by avoiding ITM options. Similarly, spread traders concerned with liquidity, may wish to restrict their spreads to ATM and moderately OTM options since ITM trading is much lighter.

Proposition 10: *Vertical traders concerned with liquidity or early exercise should avoid ITM strikes.*

Implied Volatility Differences

In our analyses of spread Greeks, we have assumed equal volatilities at all strikes. As shown in Chaput and Ederington (2005), over our data periods, the implied volatility smile in this market generally had a classic U shape with its nadir close to the underlying futures price. If traders view these implied volatility differences as real, rather than simply reflecting deficiencies in the pricing model, then they may prefer to long options with low implied volatilities and short those with higher implied volatilities. If so, they should normally organize their verticals so that they long the closest to the money strike and short options further away leading to:

Proposition 11: *Vertical spread traders who wish to long options with lower implied volatilities than they short should choose OTM strikes for debit spreads and ITM strikes for credit spreads.*

These propositions are summarized in Exhibit 5. Note that many objectives imply different strike choices for debit and credit spreads.

Results

Determining whether vertical spreads are constructed using ATM, OTM, or ITM strikes is complicated by two problems. First, as noted above, we cannot distinguish between trades which open and close a position. If, for instance, a trade is opened with OTM strikes and the underlying moves in the direction expected by the trader, we might observe a closing trade at ATM or ITM strikes. If changes in the underlying LIBOR rate are roughly random, the distribution of closing trades will be more diffuse than that for opening trades across the three moneyness categories.

Second, in our data set, the underlying LIBOR futures at the time of the vertical spread trade is not normally recorded; nor is the time. Consequently, we do not know for sure whether the position was OTM, ITM, or ATM at the time of the trade. We approximate the underlying futures price using an average of the open, high, low, and settlement prices that day. For a check on the resulting figures, we classify the positions as OTM, ITM, and ATM using the high futures price that day and again using the low price and present results for the sample where the two classifications are identical.

For this and succeeding analyses, we drop “mid-curve” options, which are options with expiries less than one year on futures maturing in more than one year, because some of the data needed for later calculations are unavailable for these options. We also remove spreads expiring in less than two weeks and move the 95 spreads incorporating a futures position into a separate sample which will be analyzed in section VI. The revised sample contains 900 observations.

Results are reported in Exhibit 6. Consistent with propositions 3, 4, 6, 8, 10 and 11, most (specifically 76.7%) of the debit spreads that we observe are OTM. When the classification as OTM, ITM, or ATM is identical based on either low or high futures prices that day, the OTM percentage rises to 81.1%. Since some of our observed debit spread trades may be closing positions opened earlier when the underlying futures price was different, it seems clear that the overwhelming majority of debit spreads are formed using OTM strikes. Consistent with this, the time-to-expiration is significantly shorter for ATM and ITM spreads than for OTM spreads.

Consistent with propositions 3, 4, 6, 8, and 11, OTM strikes are significantly (at the .0001 level) more prevalent for debit spreads than for credit spreads. Nonetheless, 55.4% of the observed credit spread strikes are OTM based on the average futures price that day and when the sample is restricted to trades where the high and low futures prices yield identical classifications, the percentage rises to 60.9%. Only 8.5% (7.7% based on high and low) are ITM. Ignoring the 32.6% which are ATM, the percentage of OTM credit spreads significantly exceeds that for ITM credit spreads at the .0001 level. This is inconsistent with all propositions except 3 and 6 (which do not apply to credit spreads) and 9 (which is contradicted for debit spreads) and 10.

With OTM strikes, the vertical spread's gamma, vega, and theta normally have the same signs as a naked option position with the same delta though they are muted. For instance if a trader longs a single call option, his position is characterized by positive values for delta, vega, gamma, and theta. If he forms a bull spread using OTM calls, all four Greeks are again positive (though smaller). If he had instead used in-the-money strikes (ITM), vega, gamma, and theta would have been negative. Consequently, the hypothesis sometimes seen in the literature that traders use vertical spreads in order to form positions with different signs for vega, gamma, and theta than for naked options with the same delta is rejected.

Perhaps our strongest results to this point are the number of vertical spread motives which we can reject. At least one of our findings is inconsistent with the hypotheses that most vertical spread traders design their vertical spreads to 1) create positively skewed returns, 2) maximize delta, 3) minimize vega risk, 4) create spreads with positive gamma, 5) create spreads with negative theta, or 6) exploit the smile by selling options with high implied volatilities and buying those with low implied volatilities. Thus, many of the advantages of vertical spreads hyped in the literature appear unimportant to the majority of vertical spread traders. The proposition that vertical traders prefer highly liquid options and/or seek to avoid early exercise is consistent with the observed overall preference for OTM strikes but cannot explain why OTM strikes are significantly more prevalent on debit spreads.

The figures for debit spreads in Exhibit 6 are consistent with the hypotheses that debit spread traders, who account for about 62% of the observed vertical spread trades, choose OTM strikes to either lower the net price (proposition 3) and/or increase delta per dollar at risk (proposition 6). Since these propositions have no implications for credit spreads, they cannot directly explain the preference for OTM strikes on credit spreads. However, if most of the observed credit spread trades are in fact closing debit spread positions opened earlier, the prevalence of OTM strikes on credit spreads could be an artifact of the debit spread preference.

Next we examine how spread Greeks and prices differ depending on the strike choices. Calculation of spread Greeks requires prices of the individual options (or their implied volatilities) but only the net price is recorded in our data set. Consequently, we estimate spread Greeks using estimated prices of the individual options and futures. For these proxy prices, we use an average of the option's or future's settlement price the day of the trade and the previous day. We use an average of the two settlement prices since they bracket the unknown time of the actual trade.[14]

Median values of the net spread price and estimated Greeks are reported in Exhibit 7 for spreads with OTM, ATM and ITM strikes. Since the signs of some Greeks differ depending on whether the spreads are bull or bear or debit or credit, medians of absolute values are reported. As explained above and illustrated in Exhibit 3, the price of a vertical spread is reduced by choosing OTM strikes and this is reflected in Exhibit 7 where the median net price is 6bp ($150) for spreads with OTM strikes, 12bp for those with ATM strikes, and 18bp for ITM strikes.

As shown above, a spread's absolute delta is maximized by choosing ATM strikes while vega, gamma, and theta are minimized (in absolute terms) with ATM strikes. These patterns are reflected in Exhibit 7 though in interpreting the Greeks it should be kept in mind that, as reported in the exhibit, times to expiration are considerably longer on OTM spreads. In proposition 6, we hypothesized that, at least for debit spreads, vertical spread traders might choose OTM strikes in order to raise the delta per dollar invested. As reported in Exhibit 7, the median absolute delta per dollar is .0251on OTM spreads versus .0203 on ATM spreads. Mean absolute values are .035 for OTM strikes and .029 for ATM. As shown in the exhibit, differences between the Black and Barone-Adesi Whaley Greeks are small.

A problem with the spread comparisons in Exhibit 7 is that the spreads differ in dimensions other than the relation of the strikes to the underlying futures, such as, time-to-expiration. Therefore in Exhibit 8, we explore how the price and Greeks would differ if the trader had chosen slightly higher or lower strikes on OTM spreads. Since Propositions 3 and 6 apply only to debit strikes, we restrict the sample to debit spreads and for homogeneity also restrict the sample to spreads where the gap between the two strikes is 25 basis points. There are 266 such spreads in our data set. We estimate what the price and Greeks would have been if the spread trader had instead chosen the strike pair 25 basis points less out-of-the-money and the pair 25 basis points further out-of-the-money keeping the strike differential at 25 bp. These are normally the closest available strike pairs to those actually chosen.[15] We also calculate the price and Greeks for the ATM pair, which may or may not be the same as the "less OTM" pair.

As reported in Exhibit 8, choosing slightly higher or lower strikes would result in quite different prices and Greeks. At the chosen OTM pair, the average price is 5.69 basis points (or $142.25 per contract). Because these are debit spreads with 25 basis point strike differentials, the mean maximum loss is 5.69 bp and the mean maximum gain, if held to expiration, is 19.31 bp.

Switching to the adjacent strike pair which is less OTM (and possibly ATM) would raise the average price to 9.71bp. Switching to the adjacent pair further OTM would lower the average price to 2.57 bp.

As noted earlier, a spread's delta is maximized by choosing ATM strikes but OTM strikes yield higher deltas per dollar. The magnitude of these differences is illustrated in Exhibit 8. Switching to the less OTM strike pair raises the mean delta from .149 to .206 but lowers the mean delta per dollar invested from .0329 to .0249. If the objective is to maximize delta per dollar invested, the debit spread trader is clearly better off with the OTM strikes and could do even better by choosing a strike pair further OTM. For the observed OTM spreads, the average delta per dollar could be raised from .0329 to .0476 by moving to strikes slightly further OTM. However, as shown in Exhibit 8, such a move increases vega risk substantially, raising the mean absolute vega per dollar from .0830 to .2158. Also, it should be noted that while delta per dollar is increased by choosing far out-of-the-money strikes, if the position is held until expiration, the price must change considerably in the direction expected in order to realize a profit.

Conclusions

In summary, both options are OTM in over two-thirds of the observed vertical spreads. Moreover, it is quite possible that some of the non-OTM spread trades represent trades closing positions opened earlier when the position could have been OTM. OTM strikes are considerably and significantly more prevalent on debit spreads than on credit spreads but OTM strikes are the rule for both. This preference for OTM strikes probably tells us more about what is not important to vertical spread traders than what is. It implies that minimizing the spread's to volatility risk is apparently not that important to most traders and that most vertical traders are not seeking spreads with different signs for vega, gamma, and theta than are available on simple option positions with the same sign deltas. The hypotheses that vertical spread traders: (1) seek positively skewed returns, (2) seek positions with positive gammas, or (3) prefer to buy (sell) options with low (high) implied volatilities all imply that ITM strikes should be preferred for credit spreads so are also rejected. The prevalence of OTM strikes on debit spreads is consistent with the proposition that debit spread traders design their spreads so as to have relatively high deltas per dollar invested. Reasons for the slight preference for OTM strikes on credit spreads remain somewhat unclear though some of these could represent closing trades of debit spread positions.

V. Vertical Spread Design - The Strike Gap

Analysis

Next we consider the choice of the gap or differential between the two strikes. Since an option's price and delta are both monotonic functions of the strike price, if a vertical spread's strike gap is increased while holding the mean strike constant, both the net price and absolute delta are increased. This is illustrated in Exhibit 9 for the case when σ=.15, t=3 months, and LIBOR=r=mean strike=6.00%. Since the price increases faster than delta, delta per dollar falls as the gap is increased as also illustrated in Exhibit 9. This leads to two propositions:

Proposition 12: *Vertical spread traders seeking to maximize their absolute delta should construct vertical spreads with large differences between the two strikes.*

Proposition 13: *Vertical spread traders seeking to minimize the net price and/or maximize delta per dollar should choose small strike price differentials.*

Since, gamma, vega, and theta are bell shaped functions of the strike price with peaks close to the underlying asset price F, whether they are increased, decreased or unchanged as the gap widens depends on whether the strikes are ATM, ITM, or OTM. If the geometric mean strike = F* and is unchanged, then an increase in the strike differential leaves vega and gamma unchanged at zero and theta little changed. If both strikes are OTM or ITM and remain so, then an increase in the strike differential increases vega, gamma, and theta in absolute terms. If an increase in the strike gap switches one of the strikes from OTM to ITM or vice-versa, then the impact on vega, gamma, and theta is unclear.

Results

As already observed, consistent with Proposition 13, the strike price differential tends to be small. In 66% of our observed spreads, it is the absolute minimum possible, which is 12 or 13 basis points for close-to-the-money options with three months or less to expiry after May 1995 and 25 basis points for all others. Moreover, because options at the 12 and 13 bp strikes are not issued until three months prior to expiry, they are generally less liquid than options at the 25 bp strike gaps so may be avoided for this reason. If we expand the "minimum gap" set to include all verticals with a gap of 25 basis points or less, 74.1% of the observed verticals fall into this set.

Mean characteristics of spreads with different gaps are reported in Exhibit 10 where we separate the spreads into strike price differentials of: (1) 12 or 13 basis points, (2) 25 basis points, (3) 37, 38 or 50 basis points (mostly 50), and (4) over 50 basis points. Since the impact of an increased differential on vega, gamma, and theta differs for OTM, ITM, and ATM options and the ATM and ITM samples are small, we report these characteristics based on OTM spreads only. Comparison of the Greeks in panel A is complicated by two facts: (1) mean strikes differ and (2) times to expiration differ considerably by strike differential averaging only one and a half months for verticals with a differential less than 25 bp and over six months of differentials above 25 bp. To minimize the impact of expiry differences on our measures of the Greeks, in Panel B we restrict the sample to spreads with expiries between 3 and 6 months - which of course eliminates spreads with gaps less that 25 bp.

Although it should be kept in mind that the characteristics in Exhibit 10 also depend on the mean strike, the characteristics reported in Panel B of Exhibit 10 generally behave as expected. The price and all Greeks rise as the strike differential increases and the delta/price generally falls.[16]

In summary, most vertical spread are constructed using the smallest possible strike differential which is consistent with an objective of maximizing the delta/price ratio and also results in relatively low values for vega, gamma, and vega on OTM spreads.

VI. Verticals with Futures

Ninety five of the observed vertical spread orders include a simultaneous order to buy or sell futures. These tend to have longer terms to expiration (5.31 months) and larger strike price differentials (40.4 basis points) and net prices (13.91 basis points) than the verticals without futures. Why would traders include futures in the order? Since, adding futures to a position impacts its delta but not the other Greeks, it seems obvious that the objective is to change the spread's delta. We further hypothesize:

> ***Proposition 14:*** *Futures are added to verticals to reduce their delta to close to zero turning them from a directional into a volatility spread.*

In 15 cases, the observer failed to record the number of futures contracts and in another 23 the Greeks could not be calculated because they involved mid curve options or data was missing leaving a sample of 57 spreads for analysis. In 53 of the 57, the effect of the futures is to reduce the trade's absolute delta.[17] In most of these, futures are bought or sold in proportions which reduce the net delta to close to zero. For example in one bull spread, the trader bought 3000 call contracts at a low strike and sold 3000 at a high strike. The resulting Black delta was about .240. At the same time he shorted 690 futures contracts or .23 futures contracts for each option contract. Consequently, the net Black delta of the combined position was approximately .240-.230 = .010. For the 53 vertical spreads, the mean absolute Black delta without the futures is .243 but only .036 with the futures. The median is .244 without futures and .018 with. Clearly, in most cases futures are combined with the vertical spreads in a ratio designed to reduce the overall delta approximately to zero.

VII. Seagulls

Description

Our sample includes 113 trades which are sometimes referred to as "seagulls" since, as illustrated in Exhibit 11, the resulting payoff pattern resembles a seagull in flight banking to the left or right. As illustrated in Exhibit 11, the payout pattern on these spreads is similar to that on vertical spreads but with an added tail so that profits or losses are only bounded in one direction. Seagulls are the most common "generic" spread traded on the Eurodollar options market. The Chicago Mercantile officially recognizes about 20 different spreads and combinations which trade as combinations. With seagulls and other generics, the floor broker must instead describe each leg of the spread individually. Although not an officially recognized spread, trading in seagulls exceeds that of a number of those which are officially recognized, such as condors, covered calls and puts, and box spreads.

Seagulls may be viewed either as adding a third option with a higher or lower strike to a vertical spread or as adding a third option with an in-between strike to a strangle. Consider for a moment the latter approach. Whether the seagull has a bull or bear shape is determined by the option at the middle strike. For instance suppose one constructs a long strangle by buying both a put with a low strike (say 5.75) and a call with a high strike (say 6.25) and then also sells or writes a put at an in-between strike (say 6.00). The resulting payoff pattern at expiration is bullish as illustrated in Exhibit 11a.[18] Suppose that the strangle part of the spread is the same but that instead of selling a put at the middle strike (6.00), one sells a call. In this case the resulting seagull has the bear shape in Exhibit 11b. In Exhibits 11c and d, we show the payoff pattern if one shorts (instead of longing as in 11a and 11b) both a low strike put and high strike call

Examination of our 113 seagull trades reveals three telling facts. One, in all 113 the option at the lowest strike is an OTM put and that at the highest strike is an OTM call. While the examples in Exhibit 11 were constructed with a put at the low strike and call at the high strike, they could equally well have been formed using a low strike call and a high strike put. For instance, the seagull shown in Exhibit 11a could also be formed by longing a low strike call, shorting a mid-strike put, and longing a high strike put. In that case (assuming the two extreme strikes straddle the underlying), both the low and high strike options would both be ITM. By always constructing the seagull with a put at the lowest strike and call at the highest and straddling the underlying asset price, seagull traders are able to make both options OTM. This strong preference for OTM strikes echos our finding for vertical spreads. It also echos the finding in Chaput and Ederington (2005) that guts, which are strangles constructed with ITM options are extremely rare.

Two, the net price is quite low. The average net price is only 4.06 basis points (compared with 9.24 bp for vertical spreads) and the median is only 3 basis points. This is related to the previous observation. Since seagulls are always constructed so that the middle option (which is sold if the other two are bought and vice versa) is closer to the money than the two outside options, its price tends to offset the other two. Consider Exhibit 11a again. A third way to construct a seagull with this pattern would be to long a low strike call, short a mid strike call (forming a vertical spread), and longing a high strike call. However, if the low strike call is the closest to the money, as is the normal case with call bull verticals as seen below, the added third strike would add to the cost, not reduce. It seems clear that for the same pattern and strikes, seagull traders choose the construction with the lowest cost.

Three, seagulls in which gains are bounded while losses are unbounded, as in Exhibits 11c and 11d, are considerably more common (73.4%) than seagulls in which losses are bounded and gains unbounded, as in Exhibits 11a and 11b (26.6%). Again note that if every seagull positions were closed with a reversing trade, these figures would be 50-50 so if some of our observed trades are closing positions, the percentage of seagulls constructed with unbounded losses are even greater. This echos our finding that bounding losses on written options is not a common use of vertical spreads.

Comparison With Vertical Spreads and Naked Options.

As illustrated in Exhibit 11, a seagull may be viewed as a vertical spread with an added tail. For instance, the seagull illustrated in Exhibit 11c may viewed as a combination of (1) a short put with a 5.75 exercise price and (2) a call bull spread with exercise prices of 6.00 and 6.25.[19] Consequently, an instructive way to explore the properties of a seagull is to examine how its properties compare with these two components.

In a seagull, both its vertical spread and naked option components have deltas with the same sign, so the resulting seagull's delta, should be sizable. On the other hand gamma, vega, and theta have opposite signs for the added option and vertical spread components. Hence, the sign of these parameters is unclear for the seagull and should be small in absolute terms. Likewise, all are constructed so that the two prices have opposite signs so whether the seagull is a credit or debit spread depends on whether the added third option or the vertical spread's price is higher. Consider for instance the seagull illustrated in Exhibit 11c where the strike price of the single put is 5.75 and the strike prices of the bull call spread portion are 6.00 and 6.25. Black model values for the seagull and its two components are presented in Panel A of Exhibit 12 assuming a underlying asset price of 6.00%, a volatility of 15%, and four month expiry. Since the put's Black delta is .290 and the call bull spread's is .179, the seagull's delta is .469. From selling the put the trader receives a price of 9.96 basis points but the bull spread costs 9.55 basis points so the net cash inflow is a minuscule .41 basis points. The naked put's gamma, vega, and theta are large and negative (since one shorts the put) while the vertical spread's are small and positive so the resulting seagull values are negative. While in this example, the seagull's net price is minuscule and its gamma, vega, and theta are dominated by the naked option, this is a consequence of the chosen strikes and parameters. In panel B we report the resulting parameter values if the spreads between the strikes are 75 rather than 25 basis points. In this case, there is a sizable net outflow (positive net price) and gamma, vega, and theta are positive, like the vertical spread portion of the seagull.

Results.

Statistics on the 91 seagulls in our sample after eliminating the mid curve options and others with incomplete information are reported in Exhibit 13 where we report parameter values for the seagull and both its naked option and vertical spread components.[20] As expected, the seagulls' absolute deltas are sizable averaging .408. Also as predicted, since the seagulls are constructed so that the vertical spread and tail prices offset, the net price is small averaging only 4.06 basis points or $101.50. About a third of the time, the price of the tail changes the spread from a credit to a debit spread or vice-versa.

As noted above, the vertical spread and third option components of the seagull have opposite signs for vega, gamma, and theta. Since vega, gamma, and theta also have opposite signs for the two components of the vertical spread, the vertical spread values of these Greeks are generally small so that whether the seagull's Greeks are positive or negative is normally determined by their sign for the third option.

In summary, we find that all seagulls are constructed with an OTM put at the lowest strike and OTM call at the highest. For most: (1) the net price is minuscule, (2) the absolute delta is sizable, and (3) vega, gamma, and theta are fairly small and (4) losses are unbounded while profits are bounded. Whether the seagull is a debit or credit spread tends to be determined by the vertical spread option portion of the spread while the signs of vega, gamma, and theta usually correspond to those of the added option.

VIII. Conclusions

Our more important conclusions include the following. One, accounting for over 10% of the trading volume due to large contracts on options on Eurodollar futures, vertical spreads are an important trading strategy. Two, the fact that over 60% of vertical spreads are debit spreads implies that more vertical spread traders are using verticals to lower the net price and increase the profit likelihood on long positions than are using verticals to limit potential losses on short positions. Three, both strikes are out-of-the-money in over two-thirds of vertical spread trades with the percentage significantly higher on debit spreads. This result is inconsistent with the hypotheses that vertical spread traders seek to maximize the spread's absolute delta, minimize its absolute vega, achieve positive gammas or negative thetas, or seek spreads with positive skewness. The predominance of OTM strikes in debit spreads is consistent with the hypotheses that these traders seek to either minimize the net price or maximize the spread's delta per dollar invested though these hypotheses cannot explain the slight preference for OTM strikes on credit spreads.[21]

Four, when vertical spreads are accompanied by a simultaneous futures order, it is almost always in proportions designed to reduce the position's net delta to zero turning the vertical from a directional play into a volatility play. Five, seagulls are an interesting vertical spread variant which are normally designed so that they have a smaller net price, and higher delta than the underlying vertical spread and different signs for gamma, vega, and theta. Like vertical spreads, most are designed so that potential losses are unbounded while potential gains are bounded.

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Exhibit 1a - Bull Call Spread

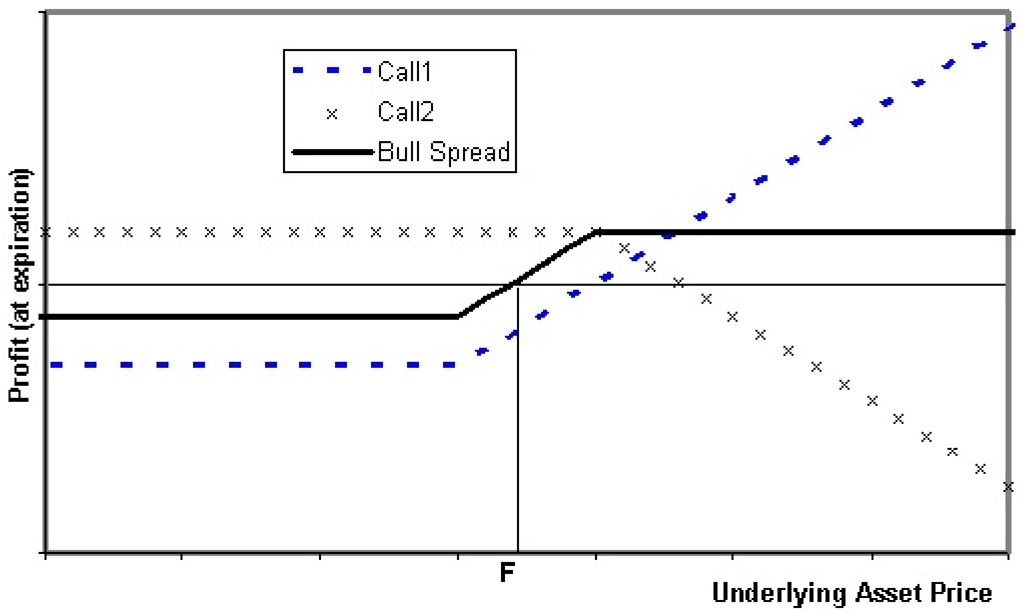

Exhibit 1b - Bull Put Spread

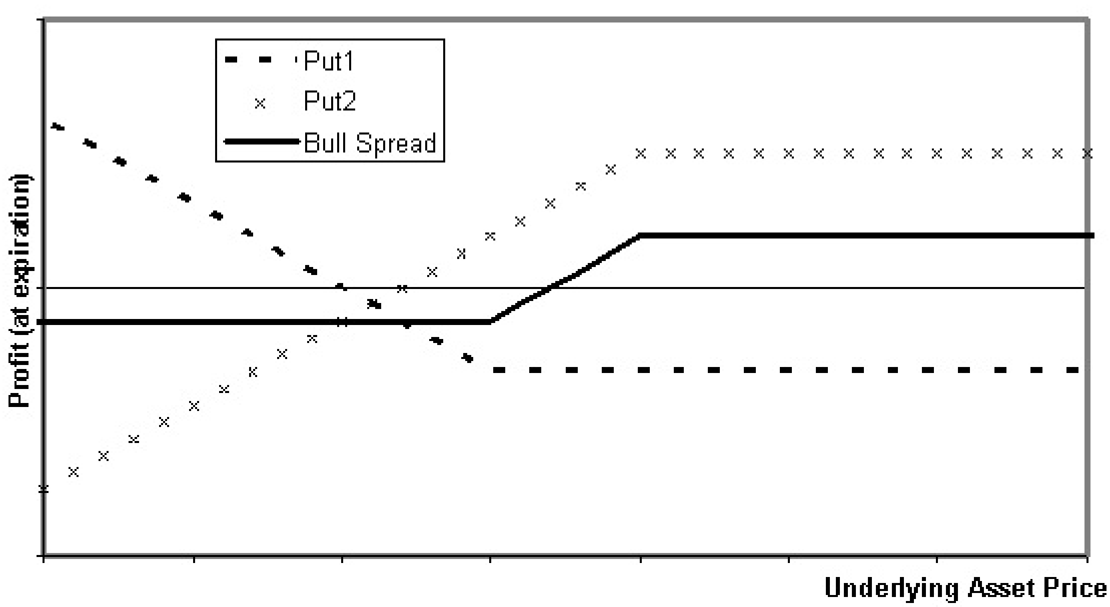

Exhibit 2 - Vertical Spread Characteristics			
Statistics are reported for 1276 vertical spread trades of 100+ contracts on the Eurodollar options on futures market. The trades were observed on 358 trading days over three periods: (1) 5/12/1994-5/18/1995, (2) 4/19/1999-9/21/1999 and (3) 3/17/2000-7/31/2000.			
	Mean	**Median**	**Standard Deviation**
Trade size in contracts	875.4	500.00	968.3
Time to maturity in months	3.78	2.93	3.18
Net price in basis points	9.24	7.50	8.27
Net price in dollars	$230.93	$187.50	$206.90
Strike price differential in basis points	31.2	25.0	17.0

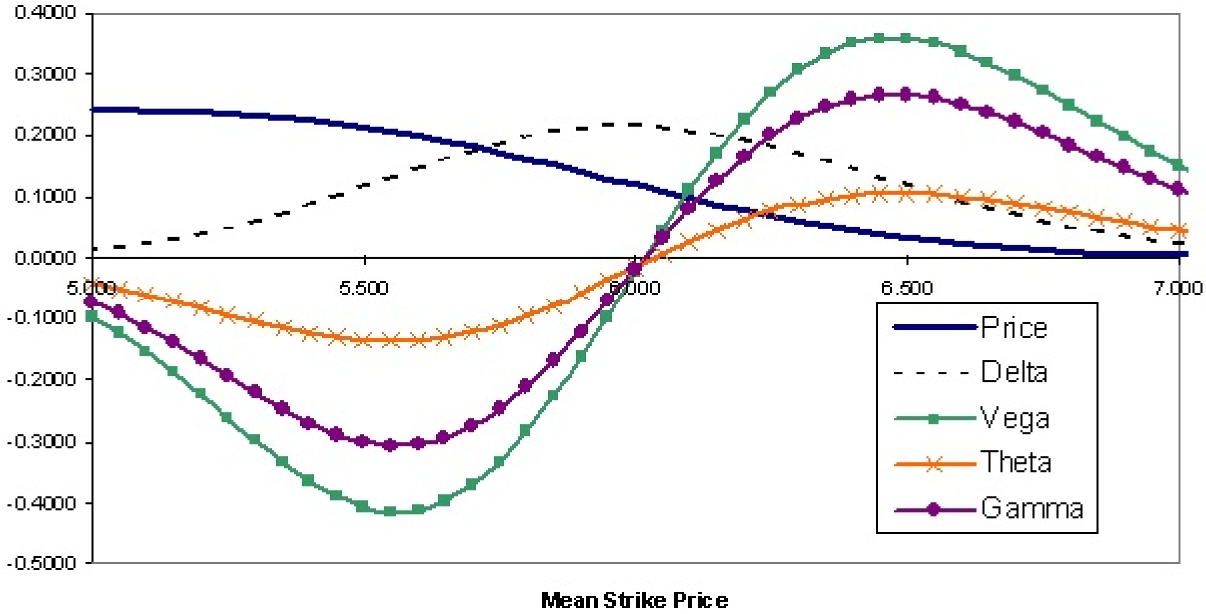

Exhibit 3 - The Impact of Strike Price Moneyness on Call Bull Spread Characteristics. Holding the strike price differential constant at 25 basis points, the price, delta, vega, and theta for a call bull spread are calculated at various possible strike price combinations according to the Black model for the following parameter values: time-to-expiration=3 months, volatility = .15, LIBOR=r=6.0%

Exhibit 4 - The Impact of Strike Price Moneyness on Call Bull Spread Characteristics. Holding the strike price differential constant at 25 basis points, the ratios delta/price and vega/price according to the Black model are calculated for a call bull spread at various possible strike price combinations for the following parameter values: time-to-expiration=3 months, volatility = .15, LIBOR=r=6.0%

Exhibit 5 - Implications of Possible Trader Objectives for the Strike Price Choice

Implications for the strike price choice of various possible objectives of vertical spread traders are summarized below. OTM indicates that the objective implies that both options should be out-of-the-money and ITM that both should be in-the-money. ATM indicates a spread in which the strike price of one leg of the vertical spread is above and one below the underlying asset price.

Objective	Proposition #	Debit Spreads		Credit Spreads	
		Call	Put	Call	Put
		Bull	Bear	Bear	Bull
Minimize Net Price	3	OTM	OTM		
Positive Skewness	4	OTM	OTM	ITM	ITM
Maximize Absolute Delta	5	ATM	ATM	ATM	ATM
Maximize Absolute Delta/Price	6	OTM	OTM		
Minimize Absolute Vega	7	ATM	ATM	ATM	ATM
Positive Gamma	8	OTM	OTM	ITM	ITM
Negative Theta	9	ITM	ITM	OTM	OTM
Minimize Early Exercise and Maximize Liquidity	10	OTM & ATM	OTM & ATM	OTM & ATM	OTM & ATM
Smile Based Trading	11	OTM	OTM	ITM	ITM

Exhibit 6 - Vertical Spread Strike Choices

Vertical spreads are classified as 1) OTM when both strikes are out-of-the-money, 2) ITM when both are in-the-money, or 3) ATM when one is out and the other in-the-money. In Panel A the classification is based on the average of the open, high, low, and settlement futures prices the day of the trade. In panel B, the sample is restricted to those observations when the classification is the same based on both the high and low futures prices that day.

	OTM strikes	ATM strikes	ITM strikes	Observations
Panel A - Classification based on average futures price on day of trade				
Debit spreads	76.7%	19.0%	4.3%	559
Call (bull)	77.2%	19.4%	3.3%	360
Put (bear)	75.9%	18.1%	6.0%	199
Credit spreads	55.4%	36.1%	8.5%	341
Call (bear)	50.7%	40.1%	9.2%	207
Put (bull)	62.7%	29.9%	7.5%	134
Panel B - Identical classifications based on high and low futures prices				
Debit spreads	81.1%	15.5%	3.5%	491
Call (bull)	81.2%	16.6%	2.2%	313
Put (bear)	80.9%	13.5%	5.6%	178
Credit spreads	60.9%	31.3%	7.7%	284
Call (bear)	54.7%	37.2%	8.1%	172
Put (bull)	70.5%	22.3%	7.1%	112

Exhibit 7 - Vertical Spread Characteristics for Different Strike Price Choices				
Medians of the net price, delta, vega, gamma, theta and time-to-expiration are reported for vertical spreads constructed using out-of-the-money strikes only, strikes straddling the underlying futures price, and in-the-money strikes only. The sample consists of 900 vertical spread trades observed over three periods: (1) 5/12/1994-5/18/1995, (2) 4/19/1999-9/21/1999 and (3) 3/17/2000-7/31/2000.				
	All	**Out-of-the-Money Strikes**	**At-the-money Strikes**	**In-the-Money Strikes**
Price (in basis points)	8.00	6.00	12.00	18.00
Black Greeks (absolute values):				
Delta	.1809	.1610	.2847	.1759
Delta/Price	.0228	.0251	.0203	.0097
Vega	.2733	.3180	.1254	.2851
Vega/Price	.0375	.0624	.0103	.0159
Gamma	.2176	.2248	.1507	.3237
Theta	.0498	.0542	.0363	.0849
Barone-Adesi Whaley Greeks (absolute values):				
Delta	.1827	.1623	.2871	.1785
Vega	.2816	.3362	.1419	.2443
Gamma	.2125	.2277	.1477	.3244
Theta	.0508	.0571	.0352	.0766
Time to expiration (months)	3.68	4.27	2.50	2.98
Observations	900	618	229	53

Exhibit 8 - Implications of Strike Choices for OTM Debit Spreads

Means and medians (in parentheses) of characteristics of 266 out-of-the-money (OTM) debit vertical spreads with a 25 basis point strike differential strikes are calculated. Also calculated are estimated characteristics if the spread had instead utilized strikes 25 bp less OTM (possibly ATM), strikes 25 bp further OTM, and the ATM strike pair maintaining the 25 bp differential. Both Black and Barone-Adesi Whaley (BW) Greeks are reported.

	Further OTM Strikes	**Actual Strikes**	Less OTM Strikes	ATM strikes
Price (in basis points)	2.57 (1.97)	**5.69 (6.00)**	9.71 (10.27)	11.46 (11.35)
LIBOR minus mean strike (absolute value)	60.11 (55.25)	**35.11 (30.25)**	14.57 (8.88)	5.90 (6.25)
Black Greeks (absolute values):				
Delta	.0777 (.0824)	**.1486 (.1438)**	.2061 (.2002)	.2189 (.2113)
Delta/Price	.0476 (.0369)	**.0329 (.0272)**	.0249 (.0202)	.0199 (.0180)
Vega	.2903 (.2899)	**.3083 (.2901)**	.1629 (.1433)	.1096 (.0944)
Vega/Price	.2158 (.1580)	**.0830 (.0570)**	.0393 (.0132)	.0099 (.0083)
Gamma	.2231 (.1803)	**.3106 (.2195)**	.1665 (.1028)	.1242 (.0702)
Theta	.0658 (.0525)	**.0687 (.0497)**	.0446 (.0316)	.0438 (.0311)
BW Greeks (absolute values):				
Delta	.0781 (.0829)	**.1492 (.1443)**	.2076 (.2010)	.2208 (.2125)
Delta/Price	.0478 (.0369)	**.0331 (.0274)**	.0251 (.1484)	.0201 (.0182)
Vega	.2968 (.2961)	**.3197 (.2980)**	.1654 (.1484)	.1052 (.0973)
Vega/Price	.2186 (.1594)	**.0850 (.0612)**	.0408 (.0124)	.0098 (.0077)
Gamma	.2240 (.1812)	**.3126 (.2210)**	.1670 (.1021)	.1234 (.0690)
Theta	.0668 (.0540)	**.0705 (.0514)**	.0435 (.0292)	.0408 (.0280)

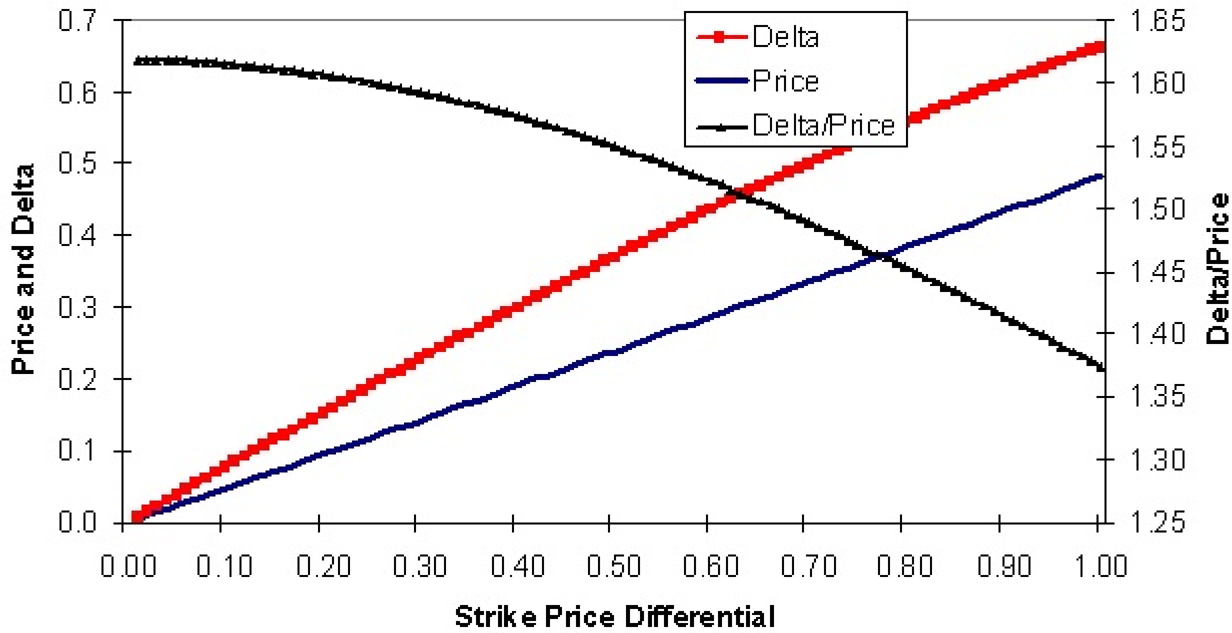

Exhibit 9 - Vertical Spread Price and Delta as Functions of the Strike Price Differential. Black model values of the delta, the net price, and the ratio of delta/price are graphed as a function of the differential between the two strikes for the case when the interest rate, the underlying LIBOR futures, and the strike equal 6%, σ=.15, and t=.25. Delta and the spread price are graphed on the left axis and their ratio on the right.

Exhibit 10 - Spread Characteristics by Strike Price Differential

Mean and median (in parentheses) values of vertical spread characteristics are reported where the sample is stratified by the difference between the two strike prices. Since the impact of an increased strike differential on vega, gamma, and theta depends on whether the strikes are in, at, or out-of-the-money, statistics for these characteristics are based on spreads in which both strikes are out-of-the-money (OTM). Greek statistics are for absolute values according to the Black model. Since mean times-to-expiration differ considerably by strike differential, we also report statistics for spreads expiring in three to six months.

	Strike Differential (in basis points)			
Characteristic	**12 or 13 bp**	**25 bp**	**50 or 37.5 bp**	**> 50 bp**
Panel A - Full Sample				
Price (in basis points)	4.03 (3.50)	7.93 (7.00)	13.27 (12.00)	26.42 (16.00)
Delta	.2197 (.2054)	.1872 (.1630)	.2178 (.1991)	.2613 (.2448)
Delta/Price Ratio	.0752 (.0562)	.0309 (.0236)	.0194 (.0167)	.0194 (.0137)
Vega (OTM only)	.2539 (.2360)	.3233 (.3017)	.4822 (.4726)	.6843 (.6961)
Gamma (OTM only)	1.0112 (.7908)	.3340 (.2269)	.2230 (.1577)	.2464 (.1870)
Theta (OTM only)	.0788 (.0673)	.0522 (.0522)	.0618 (.0497)	.1072 (.0837)
Strike Gap (basis points)	12.5 (13.0)	25.0 (25.0)	49.7 (50.0)	82.8 (75.0)
Time to expiry (months)	1.55 (1.47)	3.99 (3.50)	6.31 (5.97)	5.76 (4.95)
Observations (OTM)	83 (57)	584 (354)	201 (139)	32 (21)
Panel B - Options Expiring in 3 to 6 months				
Price		7.47 (7.00)	13.19 (12.00)	20.67 (15.00)
Delta		.1568 (.1476)	.2329 (.2379)	.2775 (.2828)
Delta/Price		.0268 (.0227)	.0212 (.0187)	.0235 (.0221)
Vega (OTM only)		.3440 (.3165)	.4829 (.4759)	.6779 (.6998)
Gamma (OTM only)		.2717 (.2560)	.2818 (.2342)	.3507 (.3492)
Theta (OTM only)		.0521 (.0493)	.0836 (.0825)	.1496 (.1306)
Time to expiry (months)		4.27 (4.25)	4.54 (4.57)	4.43 (4.70)
Observations (OTM)		224 (157)	77 (49)	12 (9)

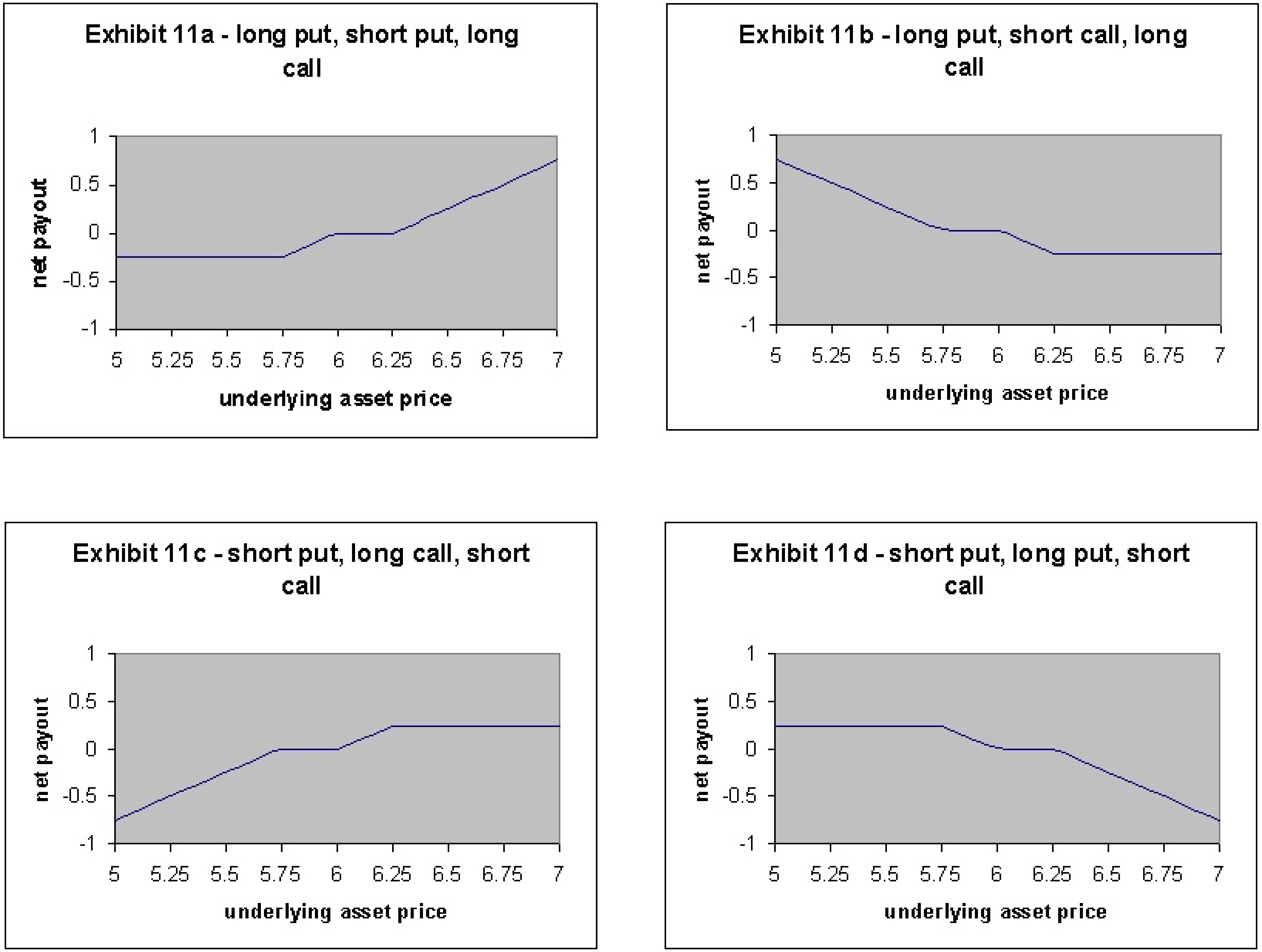

Exhibit 11 - Seagulls - Payoff patterns for four types of seagulls are shown. All four panels are constructed so that the option with the lowest strike (5.75) is a put (listed first in the panel title) and the option with the highest strike (6.25) is a call (listed last in the panel title). The option at the middle strike (6.0) may be either a call or put.

Exhibit 12 - Seagull Examples			
Black model characteristics are calculated for (1) a written or short naked OTM call option, and (2) a call bull spread consisting of one ATM call option and one OTM call option, and (3) the seagull formed by combining the two. The calculations are based on an assumed underlying asset price of 6.00, a volatility of .15, and an expiry of four months. In panel A the assumed spread between the strike prices is 25 basis points and in panel B, 75 basis points.			
	Naked Short Put	**Bull Call Spread**	**Resulting Seagull**
Panel A - Strike Prices:	**5.75**	**6.00 & 6.25**	
Delta	.290	.179	.469
Initial Cash Flow (in bp)	9.96	-9.55	0.41
Gamma	-.651	.065	-.586
Vega	-1.171	.117	-1.054
Theta	-.257	.020	-.237
Panel B - Strike Prices:	**5.25**	**6.00 & 6.75**	
Delta	.055	.414	.469
Initial Cash Flow (in bp)	1.26	-18.12	-16.85
Gamma	-.214	.435	.222
Vega	-.384	.783	.399
Theta	-.086	.165	.079

Exhibit 13 - Characteristics of Seagulls and Their Components

Mean and medians (in parentheses) of the absolute values of various characteristics for 91 seagulls traded in the Eurodollar options market over the periods 5/12/1994-5/18/1995, 4/19/1999-9/21/1999 and 3/17/2000-7/31/2000 are reported. Statistics for the vertical spread and the added third option (the tail) which make up the seagull are also reported. Finally we report the percentage of times the sign of that parameter for the seagull matched the sign of the third option (the tail); the remainder would match the sign of the vertical spread

	Seagull	**Vertical Spread Component**	**Third Option (the tail)**	**% Sign Agreement Between Seagull and Third Option**
Price (in basis points)	4.06 (3.00)	9.51 (8.99)	7.62 (5.41)	33.0%
Delta	.408 (.404)	.203 (.194)	.206 (.209)	NA
Gamma	.358 (.284)	.333 (.180)	.607 (.479)	93.4%
Vega	.817 (.727)	.379 (.342)	1.187 (1.206)	96.7%
Theta	.126 (.104)	.058 (.041)	.180 (.171)	98.9%
Time to Expiration (months)	5.91 (5.73)			

ENDNOTES

1. Eurodollar futures contracts are cash-settled contracts on the future 3-month LIBOR rate. Since LIBOR is a frequent benchmark rate for variable rate loans and interest rate swaps, hedging opportunities abound so this is a very active market.

2. Hence, these trades are not part of the "time and sales" or tick data reported by the exchanges but they are included in daily volume figures.

3. Additional information on the data are in Chaput and Ederington (2003).

4. For instance, consider a Eurodollar call with an exercise price of 94.00. Since it will be exercised if the futures price (100-LIBOR) is greater than 94, or if LIBOR<6.00%, a call in terms of 100-LIBOR is equivalent to a LIBOR put and vice versa.

5. We attempted to try to identify opening and closing trades by matching trades of the same size with the same clearing member, expiry, and strikes but only found 32 such pairs.

6. Based on conversations with traders by one author who worked in the Eurodollar pit, Black's model is by far the most popular. As shown in Chaput and Ederington (2003 and 2005), there is also evidence from our data that this is the model being employed by most volatility traders in this market.

7. Specifically, in a call bull spread, the trader pays C_1-C_2 for the spread. Then if the spread is in the money at expiration, she receives back either X_2-X_1 if both options are in the money or F_T-X_1 if only C_1 is in the money. If a put bull spread, the trader receives $P_2-P_1 = -(C_1-C_2)+(X_2-X_1)e^{-rt}$ up front and pays money back at expiration if one or both options finish in the money. For instance, suppose volatility=.15 F=r=6.1% and t=4 months. All are rounded mean values for our sample. Let the two chosen strike prices be 6.00% and 6.25%. According to the Black model, the cost of a bull call spread is C_1-C_2= 11.38 basis points which represents the maximum loss on the spread. If the futures price rises above X_2=6.25, the maximum gain on the call spread is $25e^{-.061*.333}$-11.38=13.12 basis points. If instead puts are used to construct the vertical spread, the trader receives the 13.12 basis point net price of the spread up front and any losses are deducted from this.

8. It is possible that market inefficiencies exist so that some options are mis-priced. In this case, traders might tend to choose to use whichever (calls or puts) are cheapest at the time. However, in the experience of one author who has worked in the Eurodollar options market and according to conversations with brokers and traders, this rarely happens. According to market observers, traders normally ask for quotes on either a call spread or a put spread but not both. All involved assume that (with possible adjustments for early exercise differences), put-call parity basically holds so that the price of the other spread can be calculated using put-call parity.

9. Of course, a trader's delta can always be increased by increasing the number of vertical spreads held, but this entails higher transaction costs.

10. In the Eurodollar market, the traded strikes are currently in 25 basis point increments for all options expiring in three months or longer. For options maturing in less than three months, strikes are traded in increments of 12.5 basis points for strikes relatively close to the underlying

asset price and in 25 basis points for those further away. Prior to May 1995 all were in 25 basis point increments regardless of expiry. Trading in the 12.5 strikes tends to be considerably lower than at the 25 bp strikes since they are not added until time-to-expiration is less than 3 months. Also over most of our time period, the strikes were always in integer basis point values so the smaller gaps were actually 12 and 13 basis points, not 12.5 but we shall use 12.5 for simplicity.

11. We thank the editor, Steve Figlewski for pointing out this likely objective.

12. Sometimes theta is expressed as the derivative of the option with respect to the time to expiration (so that naked options have positive thetas) and sometimes with respect to calendar time (so that naked options have negative thetas). We follow the former convention.

13. The exact point at which a vertical spread's theta is zero differs slightly from that at which vega and gamma are zero. Recall that vega and gamma were both zero when $n(d_1)-n(d_2)=0$. If 1 designate the bought option and 2 the sold option, theta=0 when $[n(d_1)-n(d_2)-r(P_1-P_2)]=0$ where n(), and d are as defined above, r is the interest rate and P_1 and P_2 are the prices of the two options. For our example spread where t=.25, F=6.0%, σ=.15, and strike price gap is 25 basis points, the Black theta is zero when the geometric mean strike is 6.033% and the BAW theta is zero when the mean is 6.021%. Again, due to the limited number of traded strikes, the differences between the mean strikes at which theta is zero and the mean strikes at which vega and gamma are zero or delta maximized are inconsequential.

14. We considered using averages of the open, high, low and settlement prices on the day of the trade instead of the two settlement prices but settlement prices have the advantage that they are observed at the same time for both the futures and options. Also, since only a net price is recorded in spread trades, these trades are not reflected in the time and sales data. Consequently, for a few of our vertical spreads the time and sales data show no trades that day (and consequently no open, high, and low prices) for one or both of our options.

15. After May 1995, the exchange started trading strikes at 12 or 13 basis point increments for options with less than 3 months to expiration and strikes close to the underlying futures price. So, depending on the date, the time to expiration, and how far OTM the spread is, it is possible in some cases to shift to a strike pair 12 or 13 basis points from than chosen - particularly for the "less OTM" pair. However, since these strikes are added after the other strikes have been trading for some time, they are generally considerably less liquid than the original strikes. In almost all cases the closest available alternative liquid strike pair is 25 bp from the chosen pair.

16. The exception is that delta/price is slightly higher when the strike differential exceeds 50 bp than when it is 50 but the former is a small sample with only 12 observations and the mean strike differs between the two samples.

17. In two of the four exceptions, the deltas of the vertical spread and the accompanying futures have the same sign, e.g., an order to long futures accompanies a bull spread. In another two cases, the deltas of the vertical and the futures have opposite signs but, because the number of futures contracts equals the number of option contracts, the position's delta switches sign and increases in absolute terms.

18. If the final price of the underlying asset is below 5.75%, both puts are ITM so the net payoff is flat at -.25. If the final price is between 5.75 and 6.00, only the sold put is in the money so the

payoff pattern is upward sloping. For prices between 6.00 and 6.25, none of the options are ITM so the net payout is zero and above 6.25 the call is ITM so the payoff line is upward sloping at 45 degrees.

19. Of course the pattern in Exhibit 11 c could also be formed by adding a short put at the 5.75 strike to a bull put spread at strikes 6.00 and 6.25 but as we have observed above this never happens. All are constructed with an OTM put at the lowest strike and a OTM call at the highest.

20. In order to combine all four seagull types, mean *absolute* values are reported (which means that excepting delta, the seagull mean is not the sum of difference of the other two means).

21. As we have noted, a possible explanation of the OTM strikes on credit spreads is that most credit spread trades represent trades closing debit spread positions.