Option Spread and Combination Trading

J. Scott Chaput*
Louis H. Ederington**

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* University of Otago
Department of Finance
Box 56
Dunedin, New Zealand
+64 (3) 479-8104
scott.chaput@otago.ac.nz

** Until 31 January, 2002:
Visiting Professor, University of Otago
lederington@business.otago.ac.nz

After 31 January, 2002:
Professor of Finance, University of Oklahoma
Michael F. Price College of Business
Finance Division 205A Adams Hall
Norman, OK 73019
405-325-5591
lederington@ou.edu

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Abstract

Documenting spread and combination trading in a major options market for the first time, we find that spreads and combinations collectively account for over 55% of large trades (trades of 100 contracts or more) in the Eurodollar options market and almost 75% of the trading volume due to large trades. In terms of total volume, the four most heavily traded combinations are (in order): straddles, ratio spreads, vertical spreads, and strangles. These four represent about two thirds of all combination trades. On the other hand, condors, horizontal spreads, guts, iron flys , box spreads, guts, covered calls or puts, and synthetics are very rarely traded while trading is light in collars, diagonal spreads, butterflies, straddle spreads, seagulls, doubles, and delta-neutral combinations. Significant differences in size, cost, and time-to-expirations are found among the various combination types.

Our results confirm that traders use spreads and combinations to construct portfolios which are highly sensitive to some risk factors and much less sensitive to other risk factors. The most popular combination designs are those yielding portfolios which are quite sensitive to volatility and less sensitive to directional changes in the underlying asset value - though they are often not completely delta neutral. Among these, combinations which are short volatility significantly out-number those which were long. Among the minority of combinations which are highly sensitive to the underlying asset price, those with positive deltas significantly outnumber those with negative deltas indicating that traders are using this market to bet on or hedge against an increase in the LIBOR rate.

We find evidence that effective bid/ask spreads are larger on orders exceeding 500 contracts or more than on orders of between 100 and 500 contracts and evidence that effective bid/ask spreads are larger on combinations which short volatility.

Option Spread and Combination Trading

I. Introduction

By creating a trading portfolio with heightened sensitivity to one or more of the determinants of option prices and reduced sensitivity to others, option spreads and combinations, such as straddles, strangles, bull and bear spreads, and butterflies enable traders to exploit expected changes in either the price of the underlying asset, its volatility, and/or the time to expiration while minimizing their exposure to the other risks. Consequently, virtually every options and derivatives text devotes at least a chapter to these spreads and combinations and they are the subject of much of the print and electronic materials distributed by option exchanges and the options industry.

Despite the attention spreads and combinations receive in derivatives texts and industry materials, they have been largely ignored by researchers. To date no one has documented which, if any, of these trading strategies are actually employed and, if so, how often. Using a unique database for one of the most active options markets, that for Options on Eurodollar Futures, we fill this gap by documenting use of these trading strategies. We find that spreads and combinations are very important. Specifically, more than 55% of the trades of 100 contracts or larger are spreads or combinations and they account for almost 75% of the trading volume attributable to trades of 100 contracts or larger. In order of contract volume, the most heavily traded combinations are: straddles, ratio spreads, vertical (i.e., bull and bear) spreads, and strangles. Indeed, the contract volume attributable to straddles and ratio spreads exceeds that accounted for by naked puts and calls. Trading is moderate to light in collars (or risk reversals), christmas trees, doubles, butterflies, delta-neutral combinations, diagonal spreads, and straddle spreads. On the other hand, condors, guts, iron flys, horizontal spreads, box spreads, synthetics, and covered calls and puts are very rarely traded.

We document such characteristics of the various spreads and combinations, such as cost, size, term to maturity, and risk profiles and compare the effective bid/ask spread on spreads and combinations with those of naked calls and puts. We show that spreads and combinations have quite different risk exposures than ordinary calls and puts and that a majority are designed to be highly sensitive to volatility and relatively insensitive to changes in the underlying assets price.[1] More of the volatility trades tend to be short volatility than long. More of the directional trades tend to have positive deltas (with respect to the LIBOR rate) than negative. We also find that effective bid-ask spreads tend to be larger on moderate size orders than on very large orders and also higher on combination orders which are short volatility. On the other hand, we find no evidence to support the hypothesis that spreads are lower if spread and combination orders are placed as a unit rather than placing separate orders for each option.

The remainder of the paper is organized as follows. In the next section, we briefly review option combinations and spreads, their treatment in the finance literature, and how they are traded on major option exchanges. Our data set is described in section III. In section IV, we document which spreads and combinations are actively traded and which are not. We document such characteristics as price, time to expiration, and size of the more popular spreads and combinations in section V. In VI, we explore the risk profiles of the traded spreads and combinations. In section VII we test the hypotheses that the effective bid/ask spread varies with order size, that bid/ask spreads respond to the order imbalance, and that the effective spread is lower on spread and combination trades than on separate orders. Section VIII concludes the paper.

II. Option Spreads and Combinations.

The options literature often draws a distinction between spreads and combinations where spreads are defined as constructed using calls or puts, but not both (e.g., a bear spread), while combinations are constructed using both calls and puts (e.g., a straddle), or options and the underlying asset (e.g., a covered call). However, for expositional simplicity, we shall often use the term "combination" to refer to both. We will use the term "legs" to refer to the individual options making up the combination.

Since calls and puts differ by both strike price and time-to-expiration and may be either bought or sold, there are a large number of possible combinations - a total of 36 possibilities when there are only two possible strike prices and two times-to-expiration. If we add the underlying asset or consider combinations of three or more options, the set of possibilities is much larger. Although only a subset of these are recognized, named, and discussed in the options literature, the number of named combinations is still large. For instance, we found one website which defined 74 different combinations but still failed to include several referenced elsewhere (and which appear in our data set). As explained below, we start by documenting those spreads and combinations officially recognized by the Chicago Mercantile Exchange and then expand to other common combinations appearing in our data set.

With the exception of box spreads, spreads and combinations have not received attention in the academic research literature heretofore but they are discussed in every derivatives text. However, the breadth of the textbook coverage varies. Virtually all texts discuss straddles and strangles, vertical (or bull and bear) spreads, horizontal or calendar spreads, butterflies/condors, covered calls, and various synthetic positions such as synthetic T-Bills. A smaller set discusses diagonal spreads, ratio spreads, straddle spreads, trees, collars, and others.

The depth of the analysis also varies among texts. Virtually all texts discuss how the profit or payout on a combination *at expiration* depends on the underlying asset's price. For instance, using straddles as an example, virtually all present graphs like the dashed line in Figure 1 showing how the payoff at expiration varies with the price of the underlying asset. Consequently, all would say that the purchaser of a straddle is betting that the final price will be far from the chosen strike price in either direction while a seller is betting it will be close to the strike.

A smaller subset of these texts describe how a combination's *current value* varies with one or more of the determinants of option value. As noted above, the various option combinations supposedly represent trading strategies designed to exploit expected changes in one or more determinants of the options' values: the price of the underlying asset, its volatility, the time-to-expiration, and/or the interest rate.[2] Like its price, a combination's "Greeks", delta, gamma, vega, theta, and rho, are simple linear combinations of the derivatives for each of its legs. For instance, if a combination consists of N_1 contracts of option 1 and N_2 of option 2, the Greek of the combination, G_c, is $G_c = N_1 G_1 + N_2 G_2$ where G_1 and G_2 represent the Greek (delta, gamma, vega, theta, or rho) of the two legs. Hence, a combination's deltas and other Greeks may either reinforce or offset. Consider, for instance, a straddle in which one buys both a call and a put with the same strike price. Since delta is positive for calls and negative for puts while gamma, vega, and theta are positive for both, straddles normally have low or zero deltas and large gammas, vegas, and thetas. Excepting doubles (aka "stupids"), in all combinations, sensitivity to one or more risk factors is enhanced (vis-a-vis the sensitivity of the legs) while sensitivity to other factors is reduced.

While they may not present the analysis in terms of delta and gamma, a number of texts present graphs like the solid line in Figure 1 showing how the *current* Black-Scholes value of the combination varies with the underlying asset's price and how the combination's value changes over time. A few texts, like Kolb (2000), Natenberg (1994), and Stoll and Whaley (1993), go further and discuss a combination's sensitivity to other factors like volatility and time-to-expiration. For example, they might present graphs like Figure 2 showing how a straddle's delta, gamma, vega, and theta vary with the underlying asset's price. In other words, while virtually most texts argue that buyers of straddles are betting on big changes in the underlying price, only a subset point out that the buyers might also be anticipating an increase in implied volatility.

While options and combinations are part of every derivatives text, they have not been the subject of much research heretofore. The one exception to this statement would be box spreads, which may be viewed as a combination of a call bull spread and a put bear spread (or call bear and put bull) with the same pair of exercise prices. This spread has the advantage that market efficiency implies strict bounds on its value regardless of the option pricing model. Consequently, box spreads have been used to test for market efficiency and arbitrage possibilities by Billingsley and Chance (1985), Ronn and Ronn (1989) and Hemler and Miller (1997).

The probable reason option combinations have not been studied heretofore is the lack of data due to the fact that, when combinations are traded on option exchanges, the traded price is a net or total price for all legs and hence does not appear in the normal published data sets. Suppose an off-the-floor trader submits an order for 100 strangles buying puts with a strike of 100 and calls with a strike of 110 and imposing a limit on the total or net price of $15. This will normally be traded *as a combination*, that is the floor broker will go to the floor and announce an intention to buy 100 strangles at the 100 and110 strikes, rather than buying 100 puts at the 100 strike and separately buying 100 calls at the 110 strike.[3] Suppose the trade is successfully executed, i.e., that a floor trader agrees to sell 100 strangles at a price of $15. Since the $15 price agreed on the exchange floor was only a net price for the package, not separate prices for the call and put, the trade does not appear in the "time and sales" or "tick" data which record only prices of individual puts and calls.[4] If instead of executing the trade as a unit, the floor broker winds up buying 100 calls from floor broker X, 50 puts from Y, and 50 from Z, any price changes do appear in the time and sales record recorded but these appear on the record as separate trades, not a strangle.[5]

III. Data

Data on large option trades in the Chicago Mercantile Exchange's market for Options on Eurodollar Futures was generously provided to us by Bear Brokerage. Eurodollar futures contracts are cash-settled contracts on the future 3-month LIBOR rate where the payoff is defined as 100-LIBOR. Since LIBOR is a frequent benchmark rate for variable rate loans, loan commitments, and swaps, hedging opportunities abound and the Eurodollar futures and options markets are the most heavily traded short-term interest rate futures and options markets respectively in the world.

Like some other executing brokers, Bear Brokerage regularly stations an observer at the periphery of the Eurodollar option and futures pits with instructions to record all options trades over 100 contracts. 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.[6] As noted above, in a combination trade, only the net price of the combination is normally observed and recorded. For instance, if a trader buys 100 straddles, we know only the price of the straddle. There is no separate determination of the separate prices of the call and put making up the straddle. Also, since the time of the trade is not recorded, we do not know the exact price of the underlying Eurodollar futures at the time of the trade unless the order includes a simultaneous futures transaction, e.g., a covered call.

The 100 contract floor above which trades are recorded refers to each leg. For instance, if an order is received for 80 bull spreads (80 calls at one strike and 80 at another), it is not recorded even though a total of 160 options are traded while an order for 100 naked calls would be. Also, the recorded size is the size of the order as long as the entire order is filled at the same price. For instance if the order is for 500 strangles and the floor broker executing the trade simultaneously buys 200 strangles from one broker, 200 from a second and 100 from a third at the same price, this is recorded as one trade/order of 500 strangles. In addition to not recording small trades, the observer does not observe so cannot record off-the-floor transactions between traders. The trades recorded on the Bear Brokerage sheets account for approximately 65.8% of the trading volume on the observed days.[7]

We only observe combinations which are ordered as combinations. If a trader who already holds Eurodollars or Eurodollar futures writes a call, we observe this as a naked call, not a covered call. If the trader simultaneously buys the futures and writes a equal number of calls, our records would show a covered call. Likewise if an off-the-floor trader places two separate orders, one for 200 calls and another for 200 puts with the same strike and expiry, our records show two separate naked trades, not a straddle while if he places a single order for 200 straddles, we observe a straddle. Consequently, our data may understate the full extent of combination trading. However, if a trader splits his order, he cannot control execution risk. For example, if he orders 200 straddles, he can set a net price limit of 10 basis points. He cannot do this if he splits the order and, if he sets limits on each leg, one leg may wind up being executed without the other. Traders also tell us that off-the-floor traders often receive better execution if the trade is executed as a combination (a proposition which is tested below). For instance, if a customer places a buy order for 500 straddles, she supposedly receives a better price (lower effective spread) than if she places two separate orders since a floor trader writing or selling the straddle also holds a position hedged against changes in the Eurodollar rate. Consequently, the traders to whom we have talked think the data capture almost all combination 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. 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.[8]

As the data were compiled, several screens were applied to the initial set of 15,188 trades. First, we remove 1306 trades between floor traders. Unlike trades initiated off the exchange floor, trades between locals may be executed either on or off the floor. The latter are not observed by Bear Brokerage's recorder. For this reason, because on and off the floor traders face different transaction costs and because the strategies of locals and off-the-floor traders may differ, we remove all trades initiated on the floor. The second screen eliminated 58 combination trades containing five or more different options or legs. A final set of screens removed 228 pricing errors and incomplete observations. For instance, an observation was normally dropped if all information was not recorded.[9] Likewise, spread trades in which it was not clear which option was bought and which was sold were deleted. If the price recorded was not in the daily range for the specific option, that trade was not included in the sample. Finally, if options were executed against futures of a differing expiration, these trades were removed. The resulting data set consists of 13,597 large trades on 385 days.

As noted above, while the number of possible combinations is very large, only a subset of these are commonly recognized. In this paper, we start by documenting trading in those combinations officially recognized by the Chicago Mercantile Exchange (CME), where our Eurodollar options are traded. The CME's combination definitions are listed in Table 1.[10] About 4.3% of the trades accounting for about 8.9% of the volume do not fit any of these definitions and are consequently labeled "generics." We take a closer look at these later.

Unfortunately, option terminology in the Eurodollar market is often confusing. As explained by Kolb (2000), Hull (2000) and Stoll and Whaley (1993) among others, although Eurodollar futures and options are officially quoted as 100-LIBOR, in calculating option values in the Eurodollar market, traders generally use pricing models, such as the Black model, defined in terms of LIBOR, not 100-LIBOR.[11] For instance, consider a Eurodollar call with an exercise price of 94.00. This call will be exercised if the futures price (100-LIBOR) is greater than 94, or if LIBOR<6.00%. So a call in terms of 100-LIBOR is equivalent to a LIBOR put and vice versa. Hence, the price of a Eurodollar call as officially quoted is obtained by setting F=LIBOR, X=6.00 (not 94.00), and σ defined in terms of LIBOR rate volatility into the pricing equation for a put. Indeed, this is the procedure used by the exchange to obtain its official volatility quotes. To avoid this inconsistency, we will treat the options as options on LIBOR. So terms like puts and calls will refer to puts and calls on LIBOR, not 100-LIBOR and similarly for "bull and bear", etc.

IV. Trading in Various Spreads and Combinations.

In Table 2 we report the percentage of trades and percentage of total contract volume in our sample accounted for by each of various combinations as well as by naked calls and puts. As shown there, spreads and combinations are extremely important in this market collectively accounting for 57.3% of the observed trades of 100 or more contracts and 74.1% of the contract volume attributable to large trades. The difference between the two percentages is due to the fact that combination trades tend to be larger than naked put and call trades.[12] Clearly the attention derivatives texts and exchange materials devote to spreads and combinations is well placed since these trading strategies are actively utilized.

In terms of percentage of trades, at 17.5%, straddles are clearly the most popular combination. Indeed the number of straddle trades is only slightly less than naked calls (22.7%) and naked puts (19.6%). Straddles also lead in terms of total contract volume (13.8%) but here the lead over ratio spreads (13.4%) is minor. Moreover, straddles and ratio spreads account for greater contract volume than naked calls and puts.

The popularity of ratio spreads (7.1% of trades and 13.4% of volume) is somewhat surprising since this combination receives much less attention in derivative texts than say butterflies (1.1% of trades and 2.5% of volume), and covered calls and puts (0.2% and 0.2%). Ratio spreads probably also receive less attention than condors (0.1% and 0.1%), horizontal or calendar spreads (3.3% and 2.4%) and box spreads (0.01% and 0.01%). Furthermore, as shown in Table 2, ratio spreads have also increased sharply in popularity rising from 4.7% of trades in 1994-95 to 9.6% in the 1999-2000 period.

Second in terms of percentage of trades, 9.4%, and third in terms of contract volume, 11.6%, are vertical, i.e., bull and bear spreads. Fourth on both measures are strangles (5.0% of trades and 6.5% of volume). Collectively, these four combinations (straddles, strangles, ratio spreads, and vertical spreads) account for 39.0% of the trades in our sample and 45.3% of the contract volume. Ignoring naked puts and calls, these four combinations account for over two thirds of all spread and combination trades and over 60% of the contract volume attributable to large combination trades.

Accounting for at least two percent of either trades, contract volume, or both are: collars (also called risk reversals or synthetics), delta neutral combinations, diagonal spreads, butterflies, straddle spreads and christmas trees (or ladders). Horizontal spreads and doubles account for between one and two percent of contract volume. Combinations which are so rarely traded that they amount to less than one percent of trades and less than one percent of volume are: covered calls/puts, guts, condors, iron butterflies, and box spreads. The latter list is somewhat surprising since several of these receive considerable attention in textbooks and market literature, especially covered calls, condors, and box spreads.

Although virtually every textbook discusses covered calls (and occasionally covered puts) in which a trader writes a call and simultaneously buys the underlying asset, out of the 13,597 large trades in our sample there are only 30 trades of covered calls or puts. In contrast, there are 449 "delta neutral" trades.[13] In other words, while we observe very few instances of covered calls in which a trader simultaneously longs the future and shorts the call in a one-to-one ratio, we observe numerous cases in which a trader longs the futures and shorts the call in a ratio designed to be delta neutral.[14] While many traders are effectively writing covered calls, the vast majority are doing so in a manner designed to minimize risk in the short run, not at expiration as in a classic covered call. Of course, some of our naked calls or puts could actually be covered since the trader might already be holding a long or short position in the underlying futures but the same argument would apply to the delta neutral combinations. During the 1999-2000 period the record keeper failed to record the number of futures contracts traded on 92 trades involving both options and futures. Since this appears to be a recorder error and there is no reason to believe that covered call/put positions were much more prevalent than in other periods, the vast majority were probably delta neutral combinations. If we partition them between covered calls/puts and delta neutral combinations in the same ratio as in the other periods the percentage of trades in our sample which are delta neutral combinations rises to 3.94% while the contract volume rises to 2.88%.

As discussed above, box spreads, which are combinations of bear and bull spreads, have received some attention in the academic research literature. However, we only observe a single box spread - which may indicate the efficiency of this market. Since butterfly trades receive considerable attention in options texts, it is instructive that butterflies (154 trades) (along with their cousins: condors (9 trades) and iron flies (28)) are not very actively traded.[15] In summary, the attention which texts spend on butterflies, box spreads, and covered calls and puts appears misplaced; the time and space would be better spent on ratio spreads which are rarely discussed but actively traded.

As shown in Table 2, 565 or 4.16% of the trades are combinations which do not fit the CME's official definitions. Since they are large, often involving three or four legs, these "generics" account for about 8.8% of the trading volume. Most of these fall into two groups: (1) straddles, strangles, and vertical spreads combined with an additional call, put, or combination and (2) combinations involving two or more times-to-expiration which do not fit either the horizontal, diagonal, or straddle spread definitions. Information on the types of combinations appearing in the generics category are presented in Table 3. The largest single category (114 of the 565 generics) are what are sometimes referred to as seagulls. These are vertical spreads combined with a third option which adds a tail to the vertical spread in the same direction, i.e., an upward sloping tail in a bull spread and downward in a bear.[16] Also, common (134 trades) are straddle/strangle/ratio doubles in which the trader buys (sells) two straddles, strangles, or ratios usually with different expirations. Another 34 trades are combinations in which a single option is combined with a straddle or strangle producing a one-winged butterfly or condor respectively. In the case of the straddle with an extra leg, the payoff pattern is the same as that of a ratio spread.

Interestingly, for 90.4% of the combinations in our sample, all legs have identical times to expiration. Horizontal and diagonal spreads and other combinations involving different terms to maturity are relatively rare.

In summary, spread and combination trades are very important indeed accounting for over 57.3% of the trades and 74.1% of the volume involving trades of 100 or more contracts. If anything, these figures underestimate the true importance of combination trades since they capture only combinations executed simultaneously. Straddles are the most popular combination in terms of both trades and volume. Second in terms of trades are vertical spreads while ratios (whose usage has increased sharply) are second in terms of volume. Strangles are the fourth most active by both measures. These four spreads and combinations represent over two-thirds of all combination trades and over 60% of the volume attributable to combinations. While butterflies and covered calls/puts are treated fairly extensively in textbooks, ratio spreads generally are not yet trading in ratio spreads is over five times that in the other two combined.

V. Combination Characteristics

Descriptive statistics for the various combinations are presented in Table 4, specifically (1) the mean and median order/trade size in contracts, (2) the mean and median time-to-expiration in months, and (3) the percentage which are accompanied by a simultaneous futures trade. For this and subsequent tables we drop guts, condors, boxes, and iron butterflies since trading in these is too light to yield meaningful statistics and also drop the generic category while adding seagulls. We observe substantial differences among the various combinations on all three dimensions. In each case, the null that there is no difference among the different combinations is rejected at the .0001 level.

Size is in option contracts per order/trade. For instance, a straddle order or trade involving 500 calls and 500 puts has a size of 1000 contracts. Any futures contracts traded simultaneously are not included in the size measure. It should be kept in mind that these are conditional means and medians since only trades of at least 100 options are recorded. As a consequence, the minimum call or put size is 100 contracts; the minimum straddle, strange, or vertical spread is 200; and the minimum butterfly or straddle spread is 400. It is also worth repeating that there may be more than one counterparty to each order/trade. For instance if the floor trader executing a 500 straddle order splits the trade between three different floor traders with 200 straddles to two and 100 to a third, this is recorded as one order/trade of 500 as long as the price is the same.

As shown in the table, most of the observed combination order/trades are fairly large involving 1000 or more contracts. Moreover, with only two exceptions, delta neutral combinations and doubles, the medians follow a very consistent pattern in that the median trade size is 500 times the number of different option units[17] involved. For trades with only one option unit, i.e., naked and covered calls and puts, the median trade size is 500 contracts. For combinations involving two option units (straddles, strangles, vertical spreads, horizontal and diagonal spreads and collars) the median trade is for 1000 contracts. For spreads with three option units (ratios[18], trees, and seagulls) the median is 1500 and for combinations with four (butterflies and straddle spreads) it is 2000.

The mean time-to-expiration (which is not reported for horizontal spreads, diagonal spreads, and straddle spreads since their legs have different times-to-expiration) varies considerably among the combination types. At a mean of 6.9 months, straddles tend to have particularly long times to expiration - considerably and significantly longer than their strangle cousins (4.4 months). Delta neutral combinations, which may also be viewed as volatility plays, also tend to have fairly long expirys (5.5months). On the other hand, the directional vertical spreads (3.8 months) and ratio spreads (3.1 months) tend to be fairly short.

Finally we report the percentage of trades which are accompanied by a simultaneous futures trade. Obviously this figure is 100% for delta-neutral combinations and covered calls and puts by definition. About 20% of collars/risk reversals are accompanied by a simultaneous futures trade. Combined with a futures trade, a collar does indeed function as a collar capping the profit/loss on the futures. Sans the futures, its payout pattern is quite different with the potential for unlimited gain or loss. Note that small but significant minorities of straddles and vertical spreads are accompanied by simultaneous futures trade and a few other combinations are as well. In an accompanying paper, we show that futures are usually added to straddles to make them delta neutral when constructed with far-from-the-money strikes. Likewise, when futures are added to a vertical spread it is normally in a proportion which results in a delta neutral position turning the vertical spread from a directional play into a volatility play.

In Table 5 we report the mean and median net price of each combination. This is expressed as the price per combination-unit. For instance, for a naked call, it is the price of one call contract; for a straddle, it is the price of both the call and put; and for a vertical spread, the net price of the two options.[19] In the 1994-95 period, most options are quoted in increments of one basis point, or $25, and in the 1999-2000 period in half basis point increments or $12.50. Consequently, most medians are in increments of $25 or $12.50. However, far-out-of-the money options and (in the latter part of our sample) some very short term options trade in half or quarter basis point increments. Straddles, strangles, and doubles are all combinations in the narrow sense of the term in that the trader buys or sells two options. All the others are spreads in that the trader buys one or more options and sells one or more so that the prices offset to some extent. Consequently, we expect straddles, strangles, and doubles to have much higher net prices than the spreads and they do. The net price also reflects whether these trades normally involve in- or out-of-the-money contracts and the time-to-expirations. For instance, the net price for straddles is more than double that for strangles for two reasons: (1) in a straddle one of the options is always in-the-money while with strangles both legs are usually out-of-the-money, and (2) as shown in Table 4, straddles generally have longer expiries.

To control for the time-to-expiration effect, we also report in Table 5 the net prices of options maturing in 3 to 5 months reporting this statistic only if we have at least 20 combinations in this time range. This adjustment results in somewhat lower prices for combinations with normally long times to expiry such as straddles and somewhat higher for combinations, like verticals, with normally short expiries but the basic pattern is unchanged.

VI. Risk Profiles of Option Spreads and Combinations.

Next we explore the risk profiles of the observed option combinations. Supposedly traders construct spreads and combinations so as to form trading portfolios with high exposure to some risk factors (such as the price of the underlying asset or its volatility) and little or no exposure to other risks. In this section we ask which risks most traders are reducing and which are they increasing by crafting their combination trades the way they do. In other words we document the risk profiles of the combinations in our sample and compare these to the risk profiles of plain vanilla options.

Discussions of option spreads and combinations often classify them as directional plays (i.e., strategies designed to profit from a forecast move in the price of the underlying asset), volatility plays (i.e., strategies designed to profit from a forecast change in actual and/or implied volatility) or both. Along these lines, vertical spreads are usually portrayed as directional strategies, straddles and strangles as volatility plays, and ratio spreads as bets on both the likely direction of a future price change and volatility. However, as we show in companion papers, the devil is in the details. Straddles and strangles can be designed as either pure volatility plays or bets on both the direction of any future price change and its magnitude. To wit, while at-the-money straddles and strangles strangling the futures price have very low deltas making them pure volatility plays, far-from-the-money straddles and strangles have sizable deltas so represent bets on the future price of the underlying asset as well. Likewise, ratio spreads can be constructed to exploit expected changes in the price of the underlying asset or its volatility or both. While vertical spreads normally have sizable deltas, they can be constructed so that they are sensitive or insensitive to volatility changes. Moreover, as shown in Table 4, a minority of vertical spreads are accompanied by a simultaneous futures trade. In the most of these cases, the effect of adding the futures is to reduce the spread's delta approximately to zero turning it from a directional into a pure volatility trade. Clearly, therefore one cannot classify all combinations of a given type as directional or volatility strategies. Accordingly, we base our classifications on a combination's "Greeks."

In this section we document how sensitive the traded combinations are to the various determinates of an option's value, i.e., we measure their Greeks: delta, gamma, vega, and theta.[20] If a combination consists of m_1 units of option 1 (where m is negative if the option is sold), m_2 of option 2, and so forth up to m_J of option J, where J is the number of legs, for any Greeks, G, such as delta, $G_c = m_1G_x + m_2G_2 + ...+ m_JG_J$ where G_j is the Greek for leg j and G_c represents the Greek for the combination. By choosing the m_j, combinations can be constructed so that sensitivities to some risk factors are increased while sensitivities to others are reduced. For instance, in a long straddle or strangle one buys both a call and a put, so J=2 and m_1=m_2=1. Since delta is positive for calls and negative for puts, the two deltas offset and the straddle/strangle can be constructed so that $\Delta_c \approx 0$. Since gamma, vega, and theta are the same sign for both calls and puts, these straddle/strangle Greeks tend to be large.

Exploration of a combination's delta, gamma, vega, and theta requires choosing an option pricing model. For this, we utilize Black's (1976) futures options model. Black's may not be the most appropriate pricing model for this market since it is European and fails to recognize both the mean reverting aspect of interest rates and their term structure. However, we are seeking the model which most market participants are using, not the model which they should be using, and according to Eurodollar traders, the Black model is the most popular by a wide margin. There is evidence in our sample to support this contention. In our Bear Brokerage sample, anytime futures and options are combined in a ratio other than one-to-one, they are placed in the "delta neutral" combination category. However, in most cases they prove to be combined in proportions which are in fact delta neutral according to the Black model. For 75% of the combinations in the "delta neutral" category, the absolute Black delta is .02 or less.[21] Accounting for the fact that futures are virtually always traded in increments of 5 contracts, the number of futures contracts chosen is normally the exact quantity which minimizes the Black delta. The Black model also has the advantage of providing tractable expressions for the Greeks and not requiring arbitrary assumptions regarding the rate of mean reversion. We calculate the Greeks using the Black model with settlement prices of the underlying futures that day, implied volatilities of each option calculated from settlement prices, and Treasury Bill rate.[22]

Potentially there are four dimensions: delta, gamma, vega, and theta, which could be used to describe a option's risk profile. However, combinations in which all legs have the same expiry (which comprise over 90% of our sample) can be basically described in terms of two dimensions: delta and a gamma-vega-theta measure because (for combinations with the same expiry) gamma and vega are proportional to each other and theta is approximately proportional to gamma and vega. To see this, consider how delta, gamma, vega, and theta depend on a combination's structure. In the Black model,

$$\text{Delta} = e^{-rt}N(d) \text{ for calls and } = e^{-rt}[N(d)-1] \text{ for puts},$$

$$\text{Gamma} = \frac{e^{-rt}}{F\sigma\sqrt{t}}n(d),$$

$$\text{Vega} = Fe^{-rt}\sqrt{t}\,n(d), \text{ and}$$

$$\text{Theta} = e^{-rt}\left[\frac{F\sigma}{2\sqrt{t}}n(d)\right] - rP$$

where $d = \frac{\ln(F/X) + .5\sigma^2 t}{\sigma\sqrt{t}}$, F is the underlying futures price, X is the strike, t is the time to expiration, r the interest rate, σ is volatility, and P is the price of the option. For all except deep in-the-money options (which are rare in our data set), the second term in the expression for theta, rP, is quite small so theta is approximately equal to:

$$\text{Theta} \approx e^{-rt}\left[\frac{F\sigma}{2\sqrt{t}}n(d)\right]$$

Hence, if the expiry and volatility are the same for all legs j,

$$\text{Delta}_c = e^{-rt}[m_1 N'(d_1) + \ldots + m_j N'(d_j) + \ldots + m_J N'(d_J)] \quad (1)$$

$$\text{Gamma}_c = \frac{e^{-rt}}{F\sigma\sqrt{t}}[m_1 n(d_1) + \ldots + m_j n(d_j) + \ldots + m_J n(d_J)] \quad (2)$$

$$\text{Vega}_c = (e^{-rt}F\sqrt{t})\,[m_1 n(d_1) + \ldots + m_j n(d_J) + \ldots + m_J n(d_J)] \quad (3)$$

$$\text{Theta}_c \approx \frac{e^{-rt}F\sigma}{2\sqrt{t}}[m_1 n(d_1) + \ldots + m_j n(d_j) + \ldots + m_J n(d_J)] \quad (4)$$

where m_j represents the number of options in leg j (which is negative for puts), d_j = d for leg j, $N'(d) = N(d)$ for calls and = [N(d)-1] for puts. Hence, as equation 1 shows, a combination's delta is proportional to $N(d)_c = \sum_{j=1}^{J} m_j N'(d_j)$, a weighed sum of the cumulative probability functions for each leg. More importantly for our purposes, according to equations 2 and 3, the combination's gamma and vega are both proportional to $n(d)_c = \sum_{j=1}^{J} m_j n(d_j)$, i.e., a weighted sum of the density functions for each leg. According to equation 4, theta is approximately proportional to $n(d)_c$ as well. This means that if two combinations have the same expiry, their gammas and vegas are proportional and approximately proportional to theta. In other words, if combination X's gamma is double the gamma of combination Y, its vega is double also and its theta is approximately double Y's.

In equation 2 , it was assumed that σ is the same for each leg. This is not precisely true since the Eurodollar data normally show a smile pattern. To test whether this assumption is crucial to the proportionality result, we calculated gamma two ways for the combinations in our sample: (1) using equation 2 and the average of the implied volatilities for the four legs and (2) using separate implied volatilities for each leg. The correlation between the two is .9989 so the proportionality result holds almost exactly if we relax this assumption. Equation 4 is based on the further assumption that the rP term in the theta equation is inconsequential so can be effectively ignored. To test this, we calculated the combinations thetas both with and without this restriction. The correlation between the two was .9516. Our interpretation of this result is that equation 4 provides a reasonable, but not perfect, proxy of a combination's theta.

According to equations 1-4, for a given expiry, a trader can change (1) delta and (2) gamma, vega, and theta by switching from one type of combination to another, e.g., from a strangle to a straddle or ratio spread, or by choosing different strike prices for the same combination. However, he cannot alter gamma, vega, and theta independently. Reducing gamma X% entails an equal reduction in vega and an approximately equal reduction in theta. Consequently, the risk profile of combinations with the same expiry can be basically described by two measures: (1) the combination's delta, Δ_c, and (2) $n(d)_c = \sum_{j=1}^{J} m_j n(d_j)$. Since for a given expiry, gamma and vega are both proportional to $n(d)_c = \sum_{j=1} m_j n(d_j)$ and theta is very highly correlated with the same measure, we use $n(d)_c$ to measure (1) a combination's sensitivity to changes in implied volatility (vega), its sensitivity to deviations of actual from implied volatility (gamma), and (3) how its value changes over time (theta) for the 90+% of combinations in our sample where all legs have the same maturity.

The $n(d)_c$ measure has the added advantage of providing a measure which can be used to compare the risk profiles of combinations with different terms to maturity. As shown by equations 2 and 3, for the same $n(d)_c$, the longer a combination's time to expiration, the higher its vega and lower its gamma.[23] This makes comparisons of gamma and vega for of combinations with different times to expiration difficult. For instance, straddles tend to have much longer expiries than vertical spreads. Consequently, straddles vegas tend to be higher on average than vertical spread vegas for this reason, not just because vegas of the different legs offset for verticals and sum for straddles. By using $n(d)_c$ as our volatility sensitivity measure, rather than gamma and/or vega, we control for differences in time-to-expiration allowing us to measure how the trader's design choices, m_j, and the strike choices impact the combination's sensitivity to implied and actual volatility.

As noted above, spreads and combinations are commonly classified as directional spreads, volatility spreads, or both. Conceptually it is clear that if $|\Delta_c| \approx 0$ and $|n(d)_c|$ is large the combination can be viewed as a volatility spread. If $|n(d)_c| \approx 0$ and $|\Delta_c|$ is large, it can be classified as a directional strategy, and that, if both measures are large, as a strategy combining a bet on both volatility and the direction of any future price change. Obviously, the question arises as to how large or small the two attributes need to be to place a trade in one category or the other. While clearly, the answer must be somewhat arbitrary, consideration of these parameters for naked puts and calls provide some guidelines. For calls, $N(d_1)$ varies from near zero for very far-from-the-money calls to near one for deep-in-the-money calls while for puts the range is from -1 to zero. For both puts and calls, $n(d_1)$ ranges from .3898 when $d_1=0$ (and $\Delta_c \approx .5$) to near zero for far-from-the-money strikes. Maximizing $|n(d)_c|$ (which can never exceed .3898) requires accepting a absolute delta of around .5. $|\Delta_c|$ can be increased and $|n(d)_c|$ reduced by choosing far-in-the-money options but these are usually thinly traded .

Because the traded strikes are fairly widely spaced, it is usually not possible to make a combination completely delta neutral or to make it completely gamma-vega neutral. Consider for instance an at-the-money straddle (which is generally regarded as a delta-neutral volatility spread). Suppose for instance that $\sigma=.16$ (the approximate mean and median in our sample), $t=5/12=.4157$ (the approximate median for straddles as reported in Table 4) and $r=.06$. Most options in our sample are traded with strikes in 25 basis point increments, e.g., 6.00%, 6.25%, 6.50%, etc. Suppose the Eurodollar futures price is F=6.00%. If one constructs a straddle using the 6.00% strike, its delta is only .5077-.4672= .0402.[24] Suppose however that the underlying Eurodollar futures is 6.10%. The two closest strikes are 6.00% and 6.25%. If the trader forms the straddle using the 6.00% strike, its delta is .1635. If he uses the 6.25% strike, Δ_c= -.1457. In general, a straddle can be made approximately delta neutral if the futures is close to an available strike but not if it is approximately in between. Of course in the latter case, it might be possible to construct a volatility spread with a lower absolute delta by using a different strategy such as a strangle or ratio spread.[25] The same general result holds for the other volatility strategies as well, i.e., depending on the relation between the available strikes and the underlying futures, it may not be possible to make a given volatility spread delta neutral.

Similarly, the extent to which a directional spread can be made gamma-vega neutral depends on the relation between the underlying futures and the available strikes. However, because the normal density is flatter than the normal distribution function for near-the-money options, the problem is not as severe. Consider gamma and vega on a vertical spread. Suppose again that σ=.16 and r=.6.0% but let t=3/12=.25 (the approximate median expiry for vertical spreads in our sample. Suppose F=6.10% so the two nearest strikes are 6.00% and 6.25%. If a trader constructs a bull call spread by longing the 6.00 strike and shorting the 6.25 strike, $n(d)_c$=.3901-.3923= -.0022. So the spread is very close to being gamma and vega neutral (gamma= -.0034 and vega= -.0083). On the other hand, suppose that the underlying Eurodollar futures is 6.00%. If the bull spread is constructed using the 6.00 and 6.25 strikes, $n(d)_c$= .0223 (gamma=.0352 and vega=.0844). If constructed using the 5.75 and 6.00 strikes, $n(d)_c$= -.040 (gamma= -.0632 and gamma = -.1516). In general, vertical spreads can be made close to gamma and vega neutral if the underlying asset price is roughly halfway between two strikes. If not, the absolute gamma and vega will be somewhat larger. In summary because traded strikes are fairly widely spaced, it is not normally possible to construct combinations for which delta, gamma, and/or vega are exactly zero.

Statistics on $|\Delta_c|$ and $|n(d)_c|$ for the combinations (and ordinary calls and puts) are presented in Tables 6 and 7 and in Figure 3. In constructing both, we exclude options maturing in less than two weeks since (due to the wide spacing of strikes) the range of Δ_c and $n(d)_c$ available to a trader is quite limited on very short term combinations and measures of Δ_c and $n(d)_c$ for these for very short term options may not be as reliable. We also exclude mid-curve options since necessary data on the underlying futures and implied volatilities were unavailable to us. These restriction eliminate 2238 observations or about 16.5% of the sample. In Table 6 and Figure 3 we show the distribution of $|\Delta_c|$ and $|n(d)_c|$ for a combined set of all the combinations along with the distributions for ordinary calls and puts for comparison. In Table 7 we report median values of $|\Delta_c|$ and $|n(d)_c|$ for the different combination types.[26]

It is clear from Table 6 and Figure 3 that combinations afford traders much richer delta gamma-vega possibilities than available from ordinary calls and puts alone. In a strict sense of course this has to be true since with naked calls and puts for every value of delta, there is only one possible $n(d)_c$ value. However, as Table 6 makes clear, the differences are quite substantial. For instance, for more than 86% of ordinary calls and puts $.1<|\Delta_c|\leq.8$ and $.2<|n(d)_c|\leq.4$ but less than 6% of the combinations fall in this range. For more than 67% of ordinary calls and puts $.2<|\Delta_c|\leq.8$ and $.3<|n(d)_c|\leq.4$ but this is true for less than 1% of the combinations. Looked at from the other direction, for about 73% of the combinations, $|n(d)_c|$ is either less than .1 or greater than .4, versus less than 3% for naked calls and puts.

It is also clear from Table 6 that many of the combination trades are volatility trades. While the maximum value of $|n(d)_c|$ is .3898 for calls and puts, $|n(d)_c|>.4$ for 50.2% of the combinations. Whether most of these can be classified as "pure" volatility trades or combined volatility-directional trades depends on where the line is drawn. If we define volatility trades as combinations with $|n(d)_c|>.3$ and $|\Delta_c|\leq.2$ (an attribute pair impossible with ordinary calls and puts), then about 41.7% of the combination trades fall in this category. If we require $|n(d)_c|>.4$ and $|\Delta_c|\leq.1$ then the figure falls to 22.7%. On the other hand, it is clear that there are relatively few purely directional strategies since $|\Delta_c|>.2$ while $|n(d)_c|<.1$ for only about 8.6% of the observed combinations although achieving this combination is relatively easy.

As shown in Table 7, the four major combination types, straddles, strangles, ratio spreads, and vertical spreads differ more sharply in terms of gamma and vega than in terms of delta. For instance, vertical spreads are commonly viewed as directional spreads and indeed their median absolute delta is the highest of the four at .183. However, the median absolute deltas of straddles, strangles, and ratio spreads are not much lower ranging from .102 for straddles to .108 for strangles. On the other hand, the median absolute value of $n(d)_c$ is only

.084 for vertical spreads (making them close to gamma-vega neutral) versus .788 for straddles and .694 for strangles. Consistent with the way they are normally viewed, ratio spreads seem to have elements of both directional and volatility spreads.

Defining volatility spreads as those for which $|n(d)_c|>.3$ and $|\Delta_c|\leq.2$, in 55.4% of these $n(d)_c < 0$ so that gamma and vega are negative implying that the traders were either betting that actual volatility would be less than the implied volatility or that implied volatility would fall. The percentage is significantly greater than 50% at the .0001 level. Defining directional spreads as those for which $|n(d)_c|<.2$ and $|\Delta_c|>.4$,in 57.3 % of these $\Delta_c>0$ implying that traders were either betting on (or hedging against) an increase LIBOR. This percentage is also significantly different from .5 at the .0001 level.

In summary, our evidence certainly confirms the view that option traders use option spreads and combinations to construct portfolios with quite different risk profiles than the available risk profiles on naked options. A large majority of combinations display either very low volatility sensitivities or very high with the latter considerably outweighing the former. Among those with very high gammas and vegas, significantly more are short volatility than long. A majority of the traded combinations have fairly low deltas but most could not be classified as delta-neutral.

VII. Effective Spreads

According to Eurodollar traders, virtually all combination trades are placed and executed as combinations, rather than as separate orders for each leg, for two reasons. The first is to control execution risk in that if separate orders are placed for each leg with separate limit orders, one order might be filled and the other not leaving the trader with an undesired exposed position. The second reason is that supposedly, combination orders, particularly combinations which are approximately delta neutral, trade at lower spreads because a floor trader taking the other side of the transaction also faces less price risk. While this argument makes sense if trades are considered on an individual basis, it is less compelling when the total book position of traders is considered since they can probably hedge the price risk on a naked call or put.

Consequently, we test the hypothesis that effective spreads are lower on combination trades, specifically straddles and strangles, than on naked call and put trades. We restrict the comparison to straddles and strangles because the hypothesis is most clear-cut for combinations which are approximately delta neutral and straddles and strangles make up the bulk of these.[27] We also test two other hypotheses. First, we test whether effective spreads vary with order size. As seen in Table 4, even given the fact that only orders of 100 or more contracts are observed, the size of the orders in our sample is surprisingly large. The median order/trade for both calls and puts is 500 contracts and the means are over 850. This raises the issue of whether very large orders create price pressure resulting in larger spreads. Second, we test whether spreads on straddle/strangle purchases differ from those on straddle/strangle sales. As reported in section 6, during our data periods orders which are short volatility significantly exceeded orders which were long volatility by about 55% to 45%. For straddles and strangles specifically, the ratio is roughly 60% short to 40% long. This suggests that the books of marketmakers in this market would tend to consistently long. In this case, they might be more willing to accept long (buy) orders than short (sell) so that effective spreads (measured relative the prices of the naked calls and puts making up the straddle or strangle) could be lower on straddle/strangle buy orders than on sell orders.[28]

Effective spreads are normally measured as the trade price minus the mean of the bid and ask prices at the time of the trade. Unfortunately, in this options market, the bid and ask prices of the marketmakers are unobservable and, since the time of the trade is not recorded in our data, we cannot observe other trade prices at the same time. Consequently, we estimate the effective spread S (in basis points) by comparing the trade price with the average price that day for the underlying option(s). For purchases, we calculate the spread as $S_{buy} =(P-P^*)$ where P is the trade price (in basis points) of the option or combination trade from our data set and P* is the estimated average price for that option or combination that day calculated from the average of the high, low, open, and settlement prices.[29] For option sales, it is measured as S_{sale} =(P*-P). We measure the roundtrip spread as $S_{rt} = S_{buy}+S_{sale}$. For straddles and strangles, P* is the sum of the average basis point prices for the call and put. Since P* only approximates the effective price at the time of the trade, S may be positive or negative for individual trades but, averaged over a large number of trades, $\bar{S}$ should be positive. The hypothesis that spreads are lower if a straddle/strangle is ordered and executed as a unit rather than as separate orders for the two legs implies that the spreads for straddles/strangles are less than double that for naked calls and puts.

Clearly P* only approximates the effective equilibrium price at the time of the trade. Since it will tend to be a poorer approximation if there is substantial movement in option prices over the course of the day, we exclude from the sample observations when the difference between the high and low option prices for the day exceeds four basis points. To avoid illiquid options and to ensure better comparability between our straddle/strangle sample and our sample of naked options we also exclude options maturing in less than one month or more than nine months and options with strikes more than 37.5 basis points from the current futures price. Finally, to eliminate likely data errors, we eliminate those few observations where the absolute value of the estimated spread on naked options exceeds 1.5 basis points and where the absolute estimated spread on straddles/strangles exceeds 3 basis points.[30]

Note that for naked calls and puts, the estimated spread is biased downward by the fact that the high, low, open, and settlement prices used to calculate the average price include the trade on which the spread is being calculated. For example, suppose the trade in question is the only trade at that strike that day. In this case the open, high, low and close are all the same and the spread is zero by definition.[31] To reduce this bias, we exclude from the sample observations where the daily high and low are equal. This reduces but does not fully eliminate the bias. If there are only two trades that day, the trade on which the spread is being calculated must be either the high or low and either the open or close. If three trades then there is a one third probability it is any one of these prices and so forth. Consequently some bias toward zero remains. Since combination trades are not included in the reported high, low, open, and settlement prices, there is no such bias in calculating the spreads on these trades.[32]

Results are reported in Table 8. As reported in Panel A, the mean effective round-trip spread on calls and puts is only .117 basis points which is surprisingly low. In the 1994-1995 period, most option prices are quoted in basis point increments and in the 1999-2000 period in half basis point increments. Hence for an individual market-maker, the normal minimum non-zero spread is 1 basis point in the first period and .5 basis points in the second. Therefore, if all market makers have the same bid ask spreads, we would expect a mean effective roundtrip spread of more than .5 basis points. Actual estimated spreads are about one eighth of this value. While we have argued that the spreads are biased downward somewhat since the observed trade is included in our calculation of P*, such a bias can only account for a small fraction of the differences between the observed spreads and 0.5.[33] The implication is that at any point in time different market-makers have different bid and ask prices so that by buying at the lowest of the ask prices and selling at the highest of the bids, many customers receive effective spreads less than one half basis point.

In panel A we also compare the spreads on orders of less than 500 contracts and more than 500 contracts.[34] Spreads on orders of between 100 (our floor) and 500 contracts are a minuscule and insignificant .018 basis points. On the larger orders, they are considerably larger at .153 basis points. However, the null that the two spreads are equal can only be rejected at the .10 level (z=1.791). Unfortunately, the fact that we cannot observe other prices at the time of the trade - just the average price for the day - does not afford a very powerful test. If indeed spreads are larger on large orders, this opens the issue of whether spreads could be reduced by splitting large orders. However, bid and ask spreads might well change following a succession of buy or sell orders so that effective spreads are higher on successive medium size orders of the same sign than those we document for random orders in panel A . The fact that traders choose not to split large orders suggests that there is little advantage.

Round-trip spreads on straddles and strangles are compared with those on puts and calls in Panels B and C. The results in panel B are based on all observations. Since the results in panel A suggest that spreads are larger on larger orders and straddles and strangles tend to be larger than naked puts and calls, in panel C we restrict both to orders between 300 and 700 contracts. Panels B and C tell similar stories. The argument that traders pay lower spreads if they place a combination order instead of separate orders for each leg implies that the roundtrip spread on a straddle or strangle is less than double the put and call spread. As shown in panels B and C, the data do not support this hypothesis. Instead spreads on straddles and strangles are close to double those on calls and puts.

Finally, in Panel D we test the hypothesis that the imbalance (60% to 40%) in straddle/strangle buy/sell orders results in higher effective spreads on sell orders than on buys. As reported in panel D, the data are certainly consistent with this view. The spread is a minuscule and insignificant .0410 for straddle/strangle purchases and a much larger and significant (.01 level) .1692 for sales. The null that $S_{sale} <= S_{buy}$ is rejected at the .05 level.[35]

In summary, at about .12 basis points, effective spreads on naked calls and puts are significantly smaller than the minimum non-zero price increment (1.0 basis points in the first part of our period and .5 basis points in the latter) implying that bid/ask price differences among market-makes result in lower spreads. Although the fact that we do not know the time of our combination trades reduces the power of our tests, we find evidence that spreads are significantly higher on very large orders (over 500 contracts) than on medium size orders (between 100 and 500 contracts). We find also find evidence that for straddles and strangles, spreads are higher on sell orders than on buy orders. However, the data are not consistent with the hypothesis that spreads are lower if the combinations are ordered and executed as a unit rather than ordering each leg separately.

VIII. Conclusions

We find that option spreads and combinations are very actively traded accounting for over 50% of trades and almost 75% of trading volume attributable to trades of 100 contracts or more on the Eurodollar options market. Clearly spreads and combinations deserve the attention they receive in derivatives texts and merit more research attention than they have received to date. By far the most actively traded combinations are straddles, ratio spreads, vertical spreads and strangles which collectively account for about two thirds of the combination trades in the Eurodollar market. Trading is considerably lighter in butterflies, delta neutrals, doubles, collars (or risk reversals), christmas trees, diagonal spreads, seagulls, and straddle spreads and virtually non-existent in condors, guts, iron flys, horizontal spreads, box spreads, synthetics, and covered call and puts.

The supposed raison d'etrê of option spreads and combinations is that they allow traders to fashion portfolios in which exposure to some risk factors is enhanced while exposure to others is reduced. Certainly our data confirm this view in that the risk profiles on observed combination trades differ sharply from those of naked calls and puts. Moreover, more than 50% of the option combinations in our sample have higher gammas and vegas than can be obtained with any naked options of the same expiry regardless of the delta or strike price. Our data indicate that among spreads and combinations, volatility plays are considerably more common than directional plays but that most volatility trades are not delta neutral. We also document significant differences among the various combinations in terms of price, size, and terms-to-expiration.

We find that effective spreads on option trades are considerably less than the minimum price increment in which options are priced. We also find evidence of price pressure in that effective spreads on orders of 500 or more are higher than on orders of between 100 and 500 contracts. On the other hand, our data do not support the hypothesis that combination traders receive lower effective spreads if they submit a single order for a combination instead of separate orders for each leg. Of course, traders still reduce execution risk by submitting a single order. Finally, we find that spreads are higher on straddle/strangle sell orders than on purchase orders.

To a great extent, this paper raises more questions than it answers. For example, are straddles (or strangles) normally designed to minimize price risk? When do/should traders use in-the-money strikes and when out-of-the-money? When do/should volatility traders use a strangle instead of a straddle? In a strangle when do they choose a small gap between the various strikes and when a large gap? Why are butterflies rarely traded? Are vertical spreads normally designed to minimize gamma and vega risk and how are the strikes chosen? In ratio spreads, how is the ratio decided and which strikes are used and why? When futures are combined with straddles, strangles, vertical spreads, and ratio spreads what is the purpose? Because of space limitations, we have avoided such design questions and questions dealing with specific combination types in the present paper focusing instead on questions dealing with combinations in general and comparisons between the different combination types. In subsequent papers we look more closely at the design of volatility spreads (straddles, strangles, and butterflies), vertical spreads and seagulls, and ratio. In other words, the present paper is the *macro* paper dealing with *inter* combination issues while those are the *micro* papers dealing with *intra* combination issues.

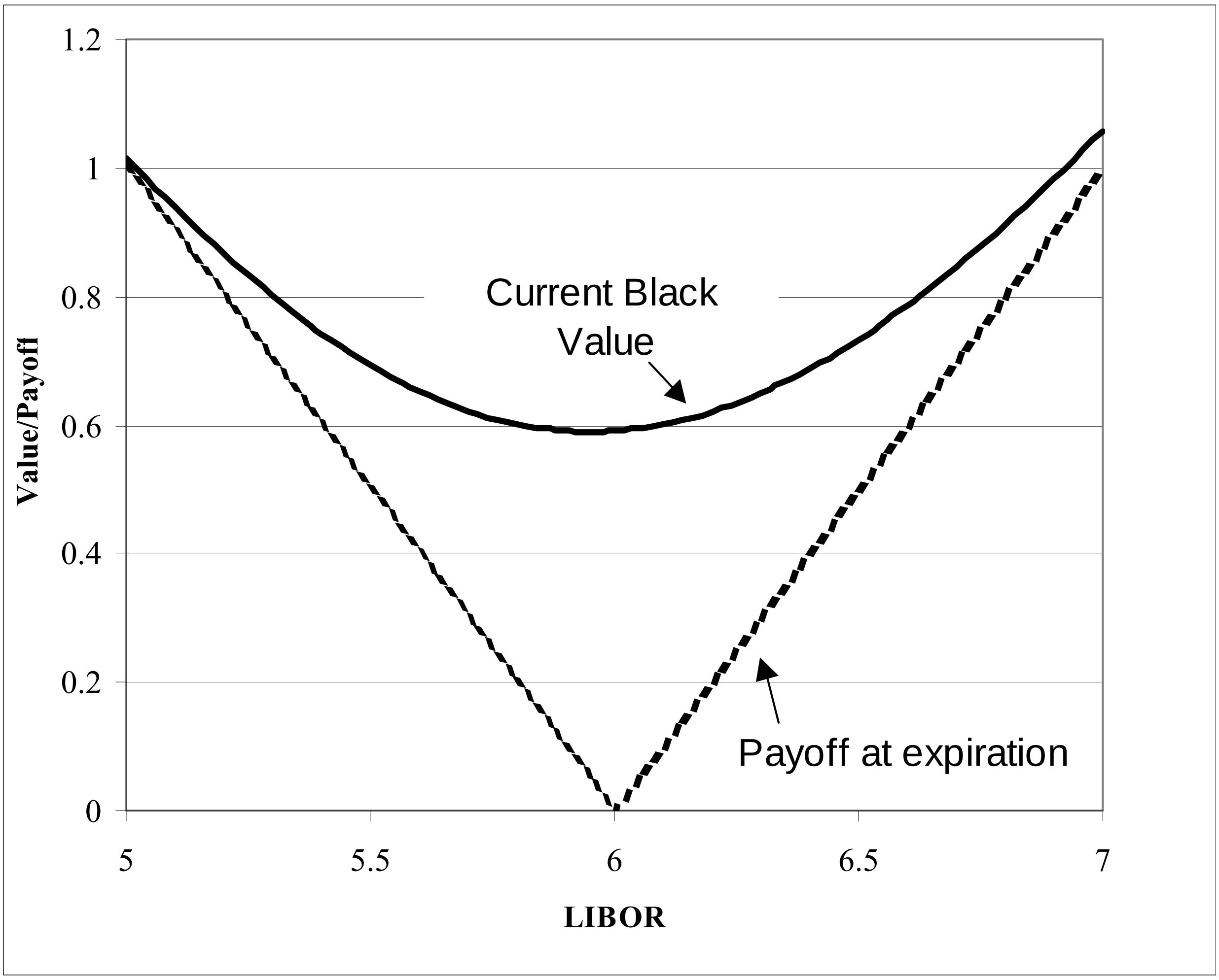


Figure 1: Straddle Values and Payoffs. The Black values of a Eurodollar straddle are calculated as a function of the LIBOR rate where X=6.00, r=6%, σ =.18, and t=.5 (years). Also shown are the payoffs or value at expiration as a function of the LIBOR rate at expiration.

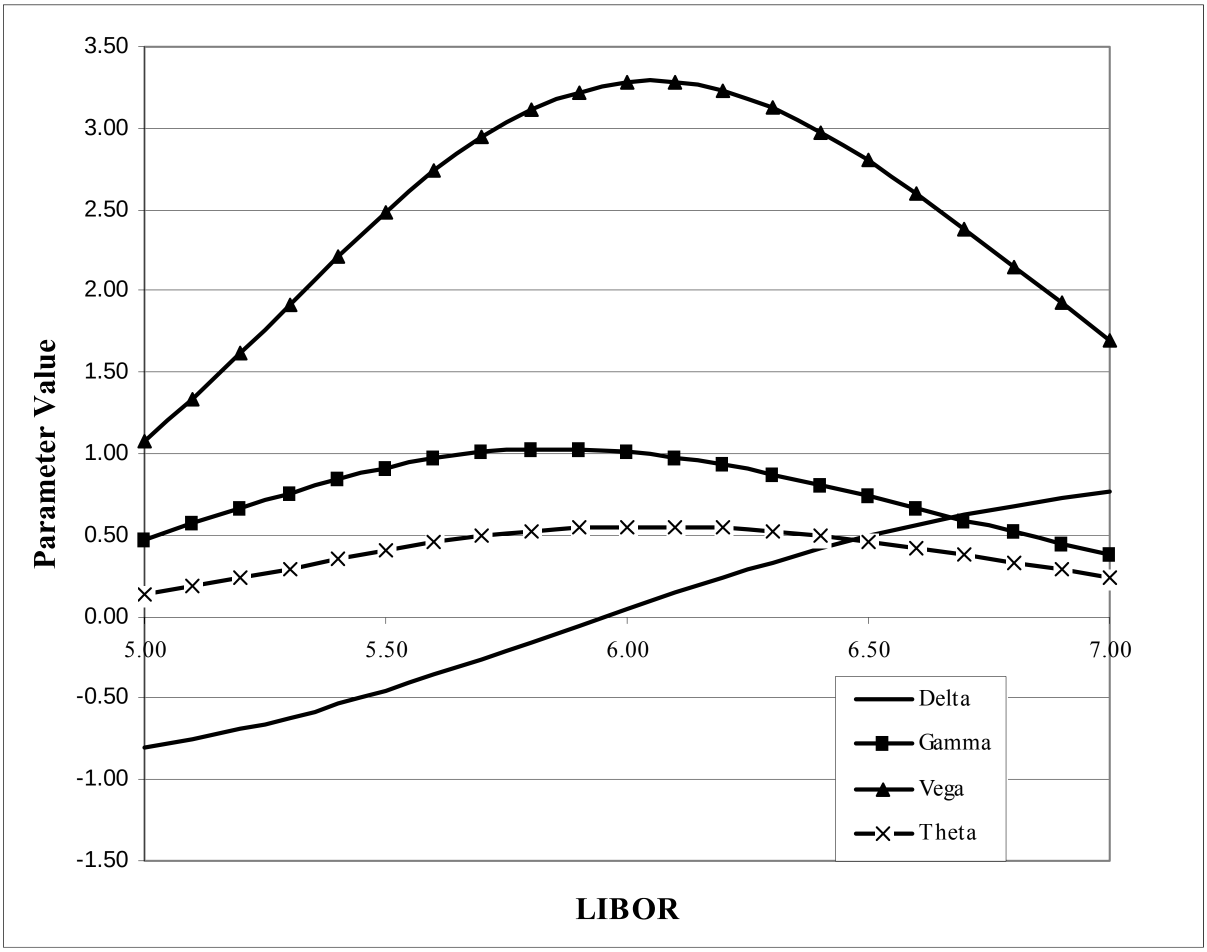
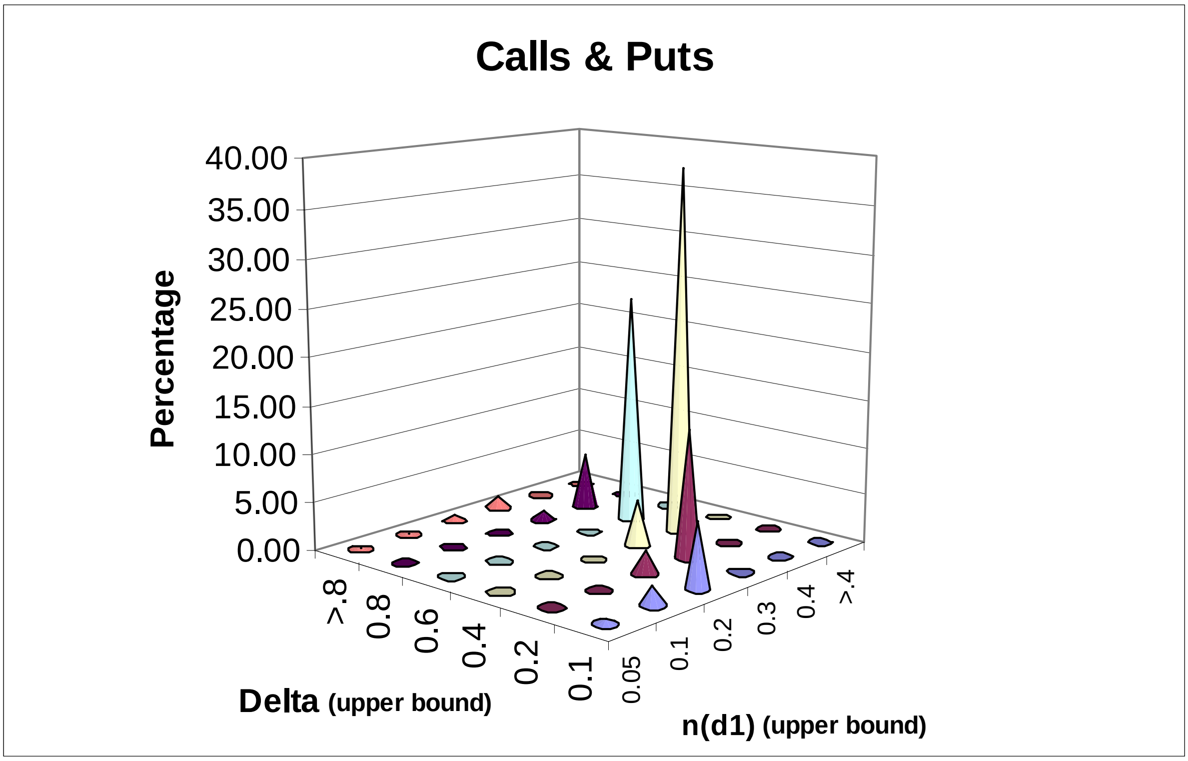


Figure 2: **Straddle Greeks as a Function of the Underlying Asset Price (LIBOR).** Delta, gamma, vega, and theta are calculated at various LIBOR values for a Eurodollar straddle using the Black model for the case when X=6.00, r=6%, σ =.18, and t=.5 (years).



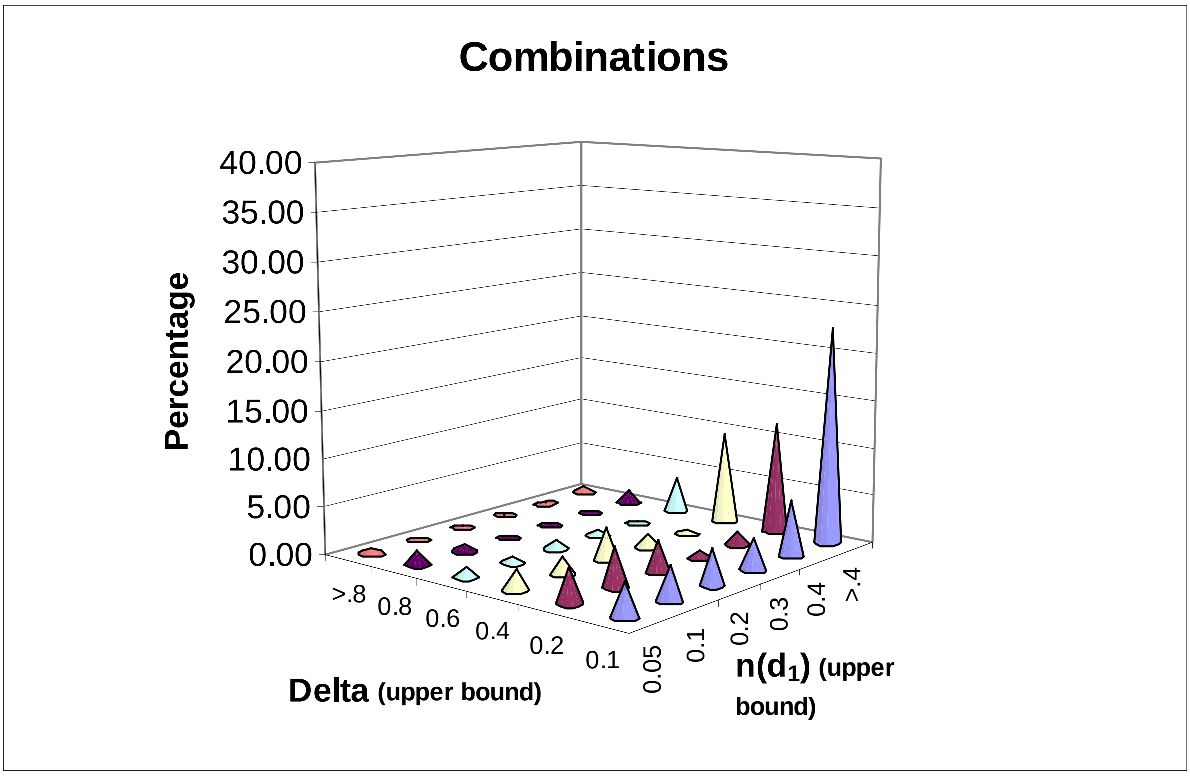


Figure 3: Comparison of the distributions of Delta and $n(d_1)$ (a measure of gamma and vega) for combinations and naked puts and calls

Table 1 - Combinations and Spreads	
The combinations and spreads recognized by and traded on the Chicago Mercantile Exchange are described. All descriptions are for long positions and are expressed as one combination unit..	
Name	**Definition**
Straddle	Buy a call and a put with the same strike price and time-to-expiration.
Strangle	Buy a put and buy a call at a higher strike price with the same expiration.
Gut	Buy a call and buy a put at a higher strike price with the same expiration.
Vertical (Bull and Bear) Spread	Buy a call (put) and sell a put (call) differing only in the strike price.
Horizontal (Calendar) Spread	Buy a call (put) and sell a put (call) differing only in the expiration.
Diagonal Spread	Buy a call (put) and sell a put (call) differing in both the strike price and the expiration.
Ratio Spread	Buy X calls (puts) and sell Y calls (puts) with a different strike.
Delta Neutral	Execute futures and options such that the position's delta is zero. [However, in practice all futures/options in which the ratio is not one-to-one are placed in this category regardless of delta.]
Butterfly	Buy a call(put), sell two calls (puts) at a higher strike price and buy a call (put) at yet a higher strike price.
Condor	Buy a call(put), sell calls (puts) at two higher strike prices and buy a call (put) at yet a higher strike price.
Iron Fly	Buy a straddle and sell a strangle.
Straddle Spread	Buy and sell straddles. Vertical straddle spreads differ only in the strike price, horizontal only in the expiration, and diagonal in both.
Christmas Tree	Buy a call (put) and sell calls (puts) at two higher (lower) strike prices.
Double	Buy calls (puts) differing only in the strike price.
Risk Reversals (Collars)	Sell a put and buy a call differing only in the strike Price. (These are sometimes referred to as synthetics.)
Covered Calls and Puts	Options and futures traded in a one-to-one ratio
Box Spreads	Buy a call bull spread and a put bear spread with identical exercise prices.
Generic	All other combinations
Combinations recognized by the CME but not present in the sample are: (true) synthetics, jelly rolls, and strips.	

Table 2
Spread and Combination Trading In Eurodollar Options

Based on 13,597 Eurodollar option trades of at least 100 contracts on 385 trading days, we report percentage breakdowns in terms of the number of trades and total contracts traded for naked calls and puts and various spreads and combinations (as defined in Table 1).

Trade or Combination Type	1994-95		1999-2000		Total sample	
	Trades	Volume	Trades	Volume	Trades	Volume
Puts (naked)	21.52%	14.71%	17.57%	11.09%	19.58%	12.89%
Calls (naked)	26.08%	13.90%	19.22%	12.07%	22.71%	12.98%
Covered calls/puts	0.19%	0.20%	0.25%	0.13%	0.22%	0.16%
Delta neutral combinations	3.67%	2.93%	2.92%	1.86%	3.30%	2.39%
Straddles	16.40%	14.92%	18.63%	12.60%	17.50%	13.76%
Strangles	5.19%	7.95%	4.75%	5.13%	4.97%	6.54%
Vertical spreads	8.18%	10.65%	10.65%	12.53%	9.39%	11.59%
Ratio spreads	4.73%	8.55%	9.60%	18.23%	7.12%	13.41%
Horizontal Spreads	0.92%	1.43%	0.93%	1.10%	0.93%	1.26%
Diagonal Spreads	1.81%	2.25%	1.18%	2.20%	1.50%	2.23%
Doubles	1.47%	2.11%	0.73%	0.73%	1.11%	1.41%
Collars/Synthetics	2.57%	4.51%	3.15%	3.73%	2.85%	4.12%
Guts	0.07%	0.06%	0.07%	0.12%	0.07%	0.09%
Trees	0.81%	1.71%	1.96%	3.83%	1.38%	2.77%
Butterflies	1.24%	2.09%	1.03%	2.85%	1.13%	2.47%
Iron Flies	0.16%	0.32%	0.25%	0.37%	0.21%	0.34%
Condors	0.09%	0.12%	0.04%	0.16%	0.07%	0.14%
Straddle Spreads	1.08%	2.68%	1.15%	1.54%	1.12%	2.11%
Boxes	0.00%	0.00%	0.01%	0.02%	0.01%	0.01%
Generics	3.83%	8.90%	4.51%	8.68%	4.16%	8.79%
Futures unrecorded*	0.00%	0.00%	1.38%	1.04%	0.68%	0.52%
Total	**100.00%**	**100.00%**	**100.00%**	**100.00%**	**100.00%**	**100.00%**

* Trades involving futures where the futures quantity was unrecorded. All occurred in 1999-2000. Most are probably delta neutral combinations

Table 3 **Breakdown of the "Generic" Combinations**	
Combinations which do not fit any of the CME's spread and combination definitions are described.	
Description	**Number**
Combinations with two legs:	
Combinations with the same expiry (including ratio collars)	18
Doubles with different expirations	38
Other combinations with different expirations (including calendar ratios)	37
Total	93
Combinations with three legs:	
Seagulls (vertical spread plus a put or call)	114
Straddle/strangle plus call or put (one winged butterfly or condor)	36
Ratio spreads plus call or put	20
Other combinations with the same expiry	28
Combinations with different expirations	83
Total	281
Combinations with four legs:	
Straddle/strangle/ratio doubles or spreads with the same expiry	42
Two vertical spreads with the same expiry	16
Other combinations with the same expiry	24
Straddle doubles with different expirations	47
Straddle/strangle spreads with different expirations	29
Other combinations with different expirations	33
Total	191

Table 4
Option Trades and Combinations - Descriptive Statistics

Based on 13,597 Eurodollar option trades of at least 100 contracts on 385 trading days, we report means and medians of trade size and time-to-expiration as well as the percentage accompanied by a simultaneous futures trade. We do not report statistics for combinations traded less than 30 times.

Trade or Combination Type	Trade Size (contracts)		Time to Expiration (months)		Percent with Futures
	Mean	Median	Mean	Median	
Puts (naked)	906	500	3.60	2.50	0.00%
Calls (naked)	838	500	3.65	2.91	0.00%
Covered calls/puts	1059	500	3.87	2.60	100.00%
Delta neutral combinations	1029	800	5.59	4.29	100.00%
Straddles	1117	1000	6.91	4.87	8.15%
Strangles	1869	1000	4.35	3.38	0.74%
Vertical spreads	1754	1000	3.84	2.97	7.44%
Ratio spreads	2677	1500	3.12	2.43	1.76%
Horizontal Spreads	1938	1000	2.22	1.06	0.00%
Diagonal Spreads	2108	1000	2.45	1.99	0.49%
Doubles	1808	1400	5.23	4.66	5.30%
Collars/Synthetics	2015	1000	4.21	3.58	20.36%
Trees	2860	1500	3.97	3.28	2.13%
Butterflies	3098	2000	3.12	2.81	0.00%
Straddle Spreads	2678	2000	4.96	3.58	1.97%
Seagulls	2631	1500	5.36	4.51	5.26%

Table 5
Prices of Option Trades and Combinations

Based on 13,597 Eurodollar option trades of at least 100 contracts on 385 trading days, we report mean and median net prices (per contract unit, e.g., one straddle) for naked calls and puts and various spreads and combinations (as defined in Table 1). We do not report statistics for combinations traded less than 30 times. We also report net price statistics of options and combinations maturing in 3 to 5 months if there are at least 20 in this time frame

Trade or Combination Type	Net Price (all contracts)		Net Price of contracts maturing in 3 to 5 months	
	Mean	Median	Mean	Median
Calls (naked)	$251.99	$150.00	$292.77	$225.00
Puts (naked)	$329.04	$225.00	$352.08	$275.00
Covered calls/puts	$627.71	$531.25		
Delta neutral combinations	$434.47	$325.00	$357.83	$300.00
Straddles	$1478.79	$1300.00	$1147.49	$1125.00
Strangles	$600.33	$475.00	$586.66	$562.50
Vertical spreads	$231.19	$187.50	$239.29	$200.00
Ratio spreads	$96.26	$62.50	$88.62	$62.50
Horizontal Spreads	$120.04	$100.00		
Diagonal Spreads	$153.03	$100.00	$181.51	$87.50
Doubles	$739.32	$575.00	$829.28	$475.00
Collars/Synthetics	$134.76	$75.00	$128.30	$75.00
Trees	$94.32	$62.50	$105.26	$50.00
Butterflies	$142.74	$100.00	$159.72	$137.50
Straddle Spreads	$441.61	$300.00	$517.50	$462.50
Seagulls	$98.90	$75.00	$81.77	$50.00

Table 6 - The Sensitivity of Combination Spreads to the Underlying Asset Price and Volatility - Distributional Statistics.

We classify the combinations in our sample in which all legs have the same expiry according to the absolute value of the combination's Delta and the absolute value of $n(d)_c$ (a measure of the combination's gamma and vega). $n(d)_c = [m_1 n(d_1) + ... + m_J n(d_J)]$ where m_j is the number of options in leg j ($-m_j$ if short), n( ) is the normal density function and $d_j = [\ln(F/X_j)+.5\sigma^2 t]/\sigma t^{.5}$ where F is the underlying futures, X_j is the strike price for leg j, σ is the estimated standard deviation of log return on F and t is the time to expiration of the option. When all legs have the same expiry, a combinations gamma and vega are both proportional to $n(d)_c$ and its Theta is roughly proportional to $n(d)_c$ as well. In ths table, we exclude horizontal and diagonal spreads and straddle spreads because (since the expiries of their legs differ), their gammas and vegas are not proportional to $n(d)_c$. Excluding combinations maturing in less than two weeks, all other combinations listed in Tables 4 and 5 are included. Reported in each cell are the percent of the combinations with that Delta-$n(d)_c$ combination. For comparison, the percentage of naked calls and puts (if any) in each cell are reported in parentheses below the combination figure.

Δ_c (delta)	$n(d)_c$ (gamma and vega)					
	$\lvert n(d)_c \rvert \leq .05$	$.05<\lvert n(d)_c \rvert \leq .1$	$.1<\lvert n(d) \rvert_c \leq .2$	$.2<\lvert n(d)_c \rvert \leq .3$	$.3<\lvert n(d)_c \rvert \leq .4$	$.4<\lvert n(d)_c \rvert$	All
$\lvert \Delta_c \rvert \leq .1$	**3.49%** (0.48%)	3.42% (2.03%)	**3.74%** (6.43%)	**3.39%**	**5.87%**	**22.72%**	**42.64%** (8.94%)
$.1<\lvert \Delta_c \rvert \leq .2$	**3.57%**	**4.07%**	**3.42%** (2.35%)	**.91%** (13.23%)	**1.34%**	**11.79%**	**25.10%** (15.58%)
$.2<\lvert \Delta_c \rvert \leq .4$	**2.05%**	**1.82%**	**3.39%**	**1.32%** (4.67%)	**.43%** (38.17%)	**9.69%**	**18.70%** (42.84%)
$.4<\lvert \Delta_c \rvert \leq .6$	**1.04%**	**.66%**	**.89%**	**.68%**	**.28%** (23.87%)	**3.82%**	**7.36%** (22.87%)
$.6<\lvert \Delta_c \rvert \leq .8$	**1.62%**	**.71%**	**.25%**	**.18%** (.88%)	**.20%** (5.76%)	**1.44%**	**4.40%** (6.64%)
$.8<\lvert \Delta_c \rvert$	**.51%** (.13%)	**.23%** (.13%)	**.15%** (.56%)	**.08%** (1.31%)	**.08%**	**.76%**	**1.80%** (2.13%)
All	**12.27%** (0.61%)	**10.91%** (2.16%)	**11.84%** (9.34%)	**6.55%** (20.09%)	**8.20%** (67.80%)	**50.23%**	**100.00%** (100.00%)

Table 7
Median Risk Profiles for Various Spreads and Combinations

We present statistics showing sensitive the various Eurodollar spreads and combinations tend to be to (1) changes in the underlying Eurodollar rate, as measured by the combination's absolute delta and (2) differences between actual and implied volatility (gamma) and changes in implied volatility (vega), as measured by $n(d)_c$. $n(d)_c = [m_1 n(d_1) + ... + m_J n(d_J)]$ where m_j is the number of options in leg j ($-m_j$ if short), n( ) is the normal density function and $d_j = [\ln(F/X_j)+.5\sigma^2 t]/\sigma t^{.5}$ where F is the underlying futures, X_j is the strike price for leg j, σ is the estimated standard deviation of log return on F and t is the time to expiration of the option. When all legs have the same expiry, a combination's gamma and vega are both proportional to $n(d)_c$ and its theta is roughly proportional to $n(d)_c$ as well. We exclude horizontal, diagonal, and straddle spreads because (since the expiries of their strikes differ), their gammas and vegas are not proportional to n(d)c. We also exclude combinations maturing in less than two weeks.

	Medians	
Trade or Combination Type	**Delta**	**$n(d)_c$**
Calls (naked)	0.325	0.354
Puts (naked)	0.302	0.337
Covered calls/puts	0.149	0.230
Delta neutral combinations	0.015	0.357
Straddles	0.102	0.788
Strangles	0.108	0.694
Vertical spreads	0.183	0.084
Ratio spreads	0.106	0.193
Doubles	0.545	0.640
Collars/Synthetics	0.602	0.043
Trees	0.083	0.186
Butterflies	0.062	0.057
Seagulls	0.404	0.190

Table 8 - Effective Spreads

In panels A-C, we report statistics on the effective roundtrip spread defined as a purchase (or sale) of a option or combination followed by a sale (purchase), $S_{rt}=S_{buy}+S_{sale}$ where $S_{buy}=(P-P^*)$ and $S_{sale}=(P^*-P)$ where P is the observed price (in basis points) of the trade from our data set and P* is the estimated average price (in basis points) that day calculated from the average of the high, low, open, and settlement prices. For straddles and strangles P* is the sum of the average prices for both legs. In panel D we report spreads separately for buy and sell orders.

	Mean S	z statistic (Ho:μ=0)
Panel A - Roundtrip Spreads on Puts and Calls by size		
All orders	.1168	3.961
Orders < 500 contracts	.0182	0.303
Orders > 500 contracts	.1534	3.351
Difference in spreads	.1393	1.791
Panel B - Roundtrip Spread on Combinations versus Puts and Calls - all observations		
Puts and Calls	.1168	3.961
Straddles and Strangles	.2102	3.416
2*(Put&Call Spread) - S&S Spread	.0234	0.274
Panel C - Roundtrip Spreads on Combinations versus Puts and Calls - 300<=Size<=700		
Puts and Calls	.1215	2.778
Straddles and Strangles	.2255	2.709
2*(Put&Call spread) - S&S spread	.0175	0.146
Panel D - Spreads on Straddles and Strangles		
Buys	.0410	0.862
Sales	.1692	4.338
Test of Ho: ($S_{sale}<=S_{buy}$)	.1282	2.082

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ENDNOTES

1. The present paper explores questions concerning spreads and combinations in general. Questions related to a specific type combination, such as straddles, and questions regarding the design of specific spreads and combinations are left to a series of accompanying papers.

2. By convention, the first derivatives of an option's price to these four determinants are known as "delta", "vega", "theta", and "rho" respectively while the second derivative with respect to the underlying asset price is termed "gamma."

3. According to CME rules, "...all spread or combination transactions in which all sides [our "legs"] are acquired simultaneously ...must be made by open outcry of the *spread differential* [our emphasis] or other appropriate pricing convention."

4. After agreeing on a net or total price, in filling out their trade cards or slips, the two traders assign notional prices to each leg of the trade. For our example in which the agreed price is $15, they might assign a price of $8 to the call and $7 to the put or the reverse or $9 and $6 or some other price pair. By exchange rules, the assigned price of at least one leg must fall within the low and high prices for that option that day. The other price is chosen so that the net price is that agreed upon. Since these are artificial prices, they are not used to calculate the high, low, open or close prices for the options that day. However, these trades are included in the day's volume statistics.

5. However, splitting the order like this would be rare since it is difficult to control execution risk, e.g., the call side of the order might be filled but not the put. Also meeting any net price limit is more difficult to ensure.

6. The futures are not subject to the 100 contract cutoff. If a trader orders a combination of 200 puts and 40 futures, both are recorded.

7. This figure excludes the midcurve options in our data set since we do not have daily total volumes for these. It includes the local to local trades and trades with missing data which we exclude from our analysis below.

8. Since the possibility exists that the missing data days might not be randomly distributed because the observer is pressed into other duties when trading is extremely heavy, we compared the days with data to those without in terms of both trading volume and price volatility. In fact it turned out that trading volume was slightly lower (instead of higher) on the days with missing data. However, the spread between the high and low prices of the nearly futures were somewhat higher on the missing days.

9. There is one exception to this. During the 1999-2000 period, the recorder often failed to record the number of futures contracts accompanying an option trade. Since to exclude these would bias downward our estimates of trading in delta neutral positions and covered calls and puts, we include them in some tables.

10. We use the recognized combinations at the beginning of our study. The CME's list has changed slightly since.

11. According to Leo Melamed (1996), the reason for this is that while in stock and commodity markets the bid price is below the ask price, in interest rate markets, the bid rate is above the offer rate. Consequently, when the first interest rate futures markets were set up, they were quoted as 100 minus the rate in order to make the bid and ask prices conform to convention.

12. Part of this is due to the fact that naked puts and calls of 100 or more contracts are in our sample while combinations must involve at least 200 contracts since each leg must involve 100 or more contracts to be included.

13. In our data, every simultaneous futures/option trade which is not one to one is classified as delta neutral. Nonetheless, most are traded in the ratio which results in a Black-Scholes delta very close to zero.

14. While most combinations in the delta neutral category in fact are, a few have surprisingly large deltas. What the traders strategy was in these cases is unclear. However, excluding these from the delta-neutral category does not alter the conclusion that truly delta neutral combinations are far more numerous than covered calls and puts.

15. Reasons for this are explored in a separate paper. Briefly, while butterflies are designated as volatility plays in most texts they are very weak volatility plays since the gammas and vegas on the sold options tend to cancel out the gammas and vegas on the bought options. At the same time, since the spread involves three different legs, transaction costs are likely higher than on two legged volatility plays such as straddles and strangles. Butterflies may also be used to exploit perceived mis-pricings. For instance, if a trader thinks the call with the middle strike is overpriced relative to the other he could construct a long butterfly to exploit this mis-pricing. Apparently, Eurodollar traders find few such mispricings to exploit.

16. In seagulls, puts are combined with call vertical spreads and calls with put verticals. If the spread is bought (sold) the added option is sold (bought). Seagulls are analyzed more carefully in the authors' paper on vertical spreads.

17. The term "option units" refers to the number of options making up one combination trade. Unless one leg contains more than one option, the number of option units is the same as the number of legs. However, for combinations like butterflies and ratio spreads, the number differs. For instance, a butterfly involves three legs but the middle leg is double the size of the other two so a butterfly consists of four option units. Likewise, while a ratio spread consists of only two legs, one is normally double the size of the other so most ratio spreads consist of three option units.

18. While the ratio in ratio spreads can vary, by far the most popular (91.6%) is the 1 to 2 spread so a single ratio normally involves three option units.

19. For ratio spreads the smallest leg is used as the base. For instance if one sells 100 of option X and buys 200 of option Y, it is the price of 2Y less one X.

20. We ignore "rho" or carrying charge risk because for all the options and combinations in our data set this risk if minimal.

21. Many of the other 25% are not delta neutral using any reasonable model. All combinations of a call or put with a simultaneous futures trade which is not in a one-to-one ratio are placed in the "delta neutral" category. While most have very low deltas, a few have such high deltas that they do not appear to be designed to be delta neutral.

22. 3-month T-bill rates are used for options expiring in less than 4.5 months, 6-month T-Bills for options maturing in 4.5 to 7.5 months, 9-month for options expiring in 7.5 to 10.5 months and 1-year rates for all longer options. The fact that we cannot observe futures prices at the time of the option trade, forces us to use settlement prices instead injecting some noise into our Greek estimates.

23. While choosing a different expiry for the same combination impacts gamma and vega, these may be offset by the changed likelihood of a change in implied or actual volatility. Specifically, gamma is lower for a longer expiry but the variance of the price change is also higher over a longer period. Vega is higher for a longer expiry but the long-term implied volatilities are less volatile than short-term implied vols.

24. The straddle's delta is exactly zero if the strike is slightly above the futures price so that d=0.

25. Indeed a strangle will have a lower delta when the underlying asset price is close to the midpoint of the two strikes than when it is near one or the other. In a separate paper, we find evidence that traders are more likely to choose strangles instead of straddles when the futures is near the midpoint of two strikes.

26. We report medians instead of means since the latter are influenced more by outliers. For instance, although almost all straddles have deltas of .2 or less, a very few are constructed using very far from the money strikes so have deltas close to 1.0.

27. The other major categories in the delta-neutral category are delta-neutral option/futures combinations but since these trade in different pits there is no reason to expect the option spread to be lower and some of the ratio spreads. As explained below, the number of usable observations is restricted because our only proxy for the equilibrium price at the time of the trade is an average of the day's high, low, open and settlement prices. For a combination, if naked trades did not occur in all legs that day we do not observe open, high, and low prices so an equilibrium price cannot be calculated. Also, since the average daily price is likely to be a particularly bad proxy if prices change considerably over the day, we exclude days with large price movements. This eliminates a large number of the ratio spread observations.

28. If a market-maker's book is heavy to one side or the other, one would normally expect her to raise or lower both the bid and ask prices, not necessarily change the spread. However, we do not observe the bid/ask spreads on spreads and combinations but measure the effective spread relative to the average prices of the underlying options. Hence, a simultaneous lowering of the straddle bid and ask prices means an increase in the effective spread on straddle sell orders and a decrease in the effective spread on straddle sell orders in our data.

29. In our 1994-95 period, one tick represents 1 basis point or $25.00 and in the 1999-2000 period, .5 basis points or $12.50.

30. Most of our calculated spreads are .5 basis points or less and 98+% are one basis point or less. However, we observe a few with much larger spreads. Given our restriction removing observations where the difference between the high and low exceeds four basis points, these seem likely to represent data errors.

31. In saying that the spread is always zero, we are assuming that the settlement price, which we use, equals the close, which we cannot observe.

32. However, this does mean that we lose a few straddle/strangle observations since, if there was no naked option trade that day in one of the legs, we cannot calculate P*.

33. The most extreme bias would occur if each day there are only two trades at each strike price/expiry: the option in our dataset and one other. In this case our option has to be either the high or the low and the open or the close so accounts for half of P*. In this case, the observed spread would be one-half the true spread so a calculated spread of .1168 would imply a true spread of .234, still far below .5.

34. We exclude orders of exactly 500 contracts which represent about 31% of the sample. Average spreads on these are between the two means reported in Table 8 but closer to the spreads on the larger trades.

35. To make sure that this result was not an artifact of the spread calculations, we repeated these calculations for naked calls and puts. For these there is no significant difference and the ratio is reversed, that is spreads are slightly but insignificantly higher on purchases.