# Ratio Spreads

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## Abstract

Ratio spreads in which one buys X calls (or puts) at one strike and sells Y calls (puts) at a different strike where $Y \neq X$ are among the most actively traded option combinations yet are only briefly mentioned in most derivatives texts and have received no attention in the research literature. Moreover when ratio spreads are discussed in texts or the practitioner literature the proposed uses vary widely. There is no agreement on when these spreads should be used, no guidance on how they should be designed, and no data on how they are used and designed. Based on data on ratio spread trades from the Eurodollar options market, we examine the design of ratio spreads and explore what the chosen designs reveal about the motives of the traders.

We find that most ratio spreads are designed so that the net price is positive but small and most have small deltas. The data is mixed on whether ratio spreads are used as volatility spreads. Their gammas and vegas have the hypothesized signs but are generally quite low.. Frontspread designs in which profits are bounded and losses unbounded considerably exceed backspread designs in which losses are bounded and profits unbounded.

## Ratio Spreads

### I. Introduction

Ratio spreads are one of the most popular option trading strategies. According to Chaput and Ederington (2003), in terms of trading volume, ratio spreads rank second only to straddles among spreads and combinations accounting for roughly 13.4% of trading volume in the Eurodollar options on futures market. Vertical (bull and bear) spreads trades are slightly more common but tend to be smaller in size so account for less trading volume. In terms of both trades and total volume, ratio spreads are considerably more common than such well known spreads and combinations as strangles, butterflies, condors, calendar spreads, covered calls, and box spreads. Indeed on the Eurodollar options market which we examine, the trading volume attributable to ratio spreads exceeds that attributable to the latter six strategies combined and is more than half that of straight (or naked) call or put trades.

Despite their popularity among traders, ratio spreads have received scant attention in the literature so it may be helpful to define them before proceeding further.[1] In a call ratio spread, the trader buys (sells) calls at one strike and sells (buys) a greater number of calls at a higher strike. The resulting profit pattern as function of the underlying asset price at expiration is illustrated in Figure 1a (1b). In a put ratio spread, one buys (sells) puts at one strike and sells (buys) a larger number of puts at a lower strike. The resulting profit pattern is illustrated in Figure 1c (1d). If the number of options sold exceeds the number purchased so that possible losses are unbounded while gains are bounded as in Figures 1a and 1c, the spread is referred to as a frontspread. If more options are purchased than sold so that potential profits are unbounded (Figures 1b and 1d) it is known as a backspread.

Many derivative texts ignore ratio spreads entirely. Those that do mention ratio spread pay much less attention to them than they pay to strangles, butterflies, condors, covered calls, and box spreads which are lightly or rarely traded. Moreover, we have been unable to find a single research article or paper dealing with ratio spreads. Ratio spreads are discussed in the practitioner literature but these offer widely differing advice on when to use ratio spread and little advice on how to design them. We seek to fill this gap in our understanding of ratio spreads by documenting the trading and construction of ratio spread trades on the Eurodollar options market and examining what this reveals about the traders' objectives.

Ratio spreads are one of the more flexible option trading strategies. Depending on whether one chooses a frontspread or backspread, either losses or profits may be unbounded and depending on whether one uses calls or puts they are unbounded on either the upside or the downside. Moreover, for a given type, such as the call frontspread in Figure 1a, delta, gamma, vega, theta and the net price can be either positive, zero, or negative depending on the relation of the two strikes to the underlying asset price and the ratio of shorts to longs.

Our findings include the following. One, whether ratio spreads are used as volatility spreads remains unclear. Their gammas and vegas generally have the signs implied by the discussions in the practitioner literature. However, they are much weaker volatility spreads than straddles or strangles in that their gammas and vegas are much smaller and frontspreads are not designed so that the payoffs at expiration are maximized if volatility is low. Two, most are designed so that the net price is positive but small. Three, most are designed so that they are approximately delta neutral. Four, traders seem to be seeking a balance between spreads with large absolute gammas and vegas and low prices and deltas. Five, ratio traders stick to a few standard ratios with over ninety percent using a two-to-one ratio even though they could achieve exact delta neutrality or a zero net price by altering the ratio away from integer values. Six, frontspreads, that is ratio spreads in which possible losses are unbounded while potential profits are bounded are considerably more common than backspreads in which losses are bounded and profits unbounded. This and the predominance of out-of-the-money strikes is consistent both with their use for pay-later hedges and as alternatives to straddles for trades shorting volatility.

The paper is organized as follows. In the next section we describe our data and document some basic characteristics of ratio spreads in the Eurodollar options market. The literature on ratio spreads is reviewed and hypotheses concerning ratio spread design are developed in section

III. Preliminary evidence on these hypotheses is presented in section IV. Section V examines what the ratio choice of the ratio reveals about the trader's motives while section VI examines what their strike choices tell us. Section VII concludes the paper.

## II. Data and Market Characteristics.

### *II.1. The Market for Options on Eurodollar Futures.*

We examine ratio spread trading in options on Eurodollar futures. Eurodollar futures contracts are cash-settled contracts on the future 3-month LIBOR rate traded on the Chicago Mercantile Exchange. 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.

Unfortunately, option terminology in the Eurodollar market can be confusing. As explained by Kolb (2003), and Hull (2003) 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 (1976) model, defined in terms of LIBOR, not 100-LIBOR.[2] 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. Here we will treat the options as options on LIBOR.

One question tested below is whether ratio spread design is influenced by the shape of the implied volatility smile. In Figure 2, we document the average smile pattern in the Eurodollar options market over our data period.[3] For each option j on every day t, we obtain the implied standard deviation, $ISD_{j,t}$, as calculated by the CME and calculate the relative percentage "moneyness" of option j's strike price measured as $(X_{j,t}/F_t)$-1 where $X_{j,t}$ is option j's strike price and $F_t$ is the underlying futures price on day t. Time series means $ISD_j$ are graphed against $(X/F)_j$

-1 in Figure 2. As shown in Figure 2, implied volatilities in this market display a standard U-shaped smile pattern - generally rising as strikes further from the underlying futures price are considered. The smile in Figure 2 is for options expiring in 2 to 4 weeks. The smile pattern for longer term options is the same but not as steep.

*II.2. The Data.*

As explained in Chaput and Ederington (2003), major option spreads and combinations are traded as such. That is there is only one trade in which a single price for the combination is negotiated, not separate trades of each of the combination's parts or legs. Recent prices of the most recent trades are displayed on the exchange floor for the most popular combinations but these prices are not included in existing public trade data. Fortunately, data on large option trades including combination trades in the Chicago Mercantile Exchange's market for Options on Eurodollar Futures was generously provided to us by Bear Brokerage. Bear Brokerage regularly stations an observer at the periphery of the Eurodollar pits with instructions to record all option trades of 100 contracts or more. For each large trade, this observer records (1) the net price, (2) the clearing member initiating the trade, (3) the trade type, e.g., naked call, straddle, ratio 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. The trades recorded by Bear Brokerage account for approximately 65.8% of the options traded on the observed days - the remainder being unrecorded smaller trades.

Several limitations of the data are worth noting. First, we only observe ratio spreads which are ordered as such. If an off-the-floor trader places one order to buy 100 calls at one strike and a separate order to sell 200 calls at a higher strike with the same expiry, our records show two naked trades, not a call frontspread. Consequently, our data may understate the full extent of ratio spread trading. However, if a trader splits his order, he cannot control execution risk. For example, if he orders 100 2to1 call frontspreads spreads, he can set a net price limit of 5 basis points. He cannot do this if he splits the order. If he sets limits on each leg, one leg may wind up being executed without the other. Consequently, the traders to whom we have talked think the data capture almost all spread trades. Second, in a ratio spread trade, the buyer and seller agree on a net price, not prices for each leg, so only the net price is available to us. Third, unless futures are a part of the order (which is rarely the case with ratio spreads), we do not know the underlying futures price at the time of the trade nor the exact time of the trade. Fourth, we cannot distinguish between trades which open and close a position. If for instance, a frontspread position is opened and closed later we would observe both a frontspread trade initially and a backspread trade later. However, both our data here and in previous studies indicate that our data is dominated by position opening trades, i.e., that traders hold many positions to expiration (or close to it).

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.[4] 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. We applied several screens to the raw data removing trades solely between floor traders (since it is unclear who initiated the trade), obvious recording errors, and incomplete observations. We obtained data on daily option and futures prices: open, high, low, and settlement from the Futures Industry Institute for the days in our data set.

The resulting data set consists of 13,597 large trades on 385 days. Of these 5750 or 42.3% are straightforward trades of calls or puts and 7847 represent trades of combinations or spreads consisting of two or more contracts. Of the 13,597 trades, 968 are ratio spreads. These represent 7.12% of all large trades and 12.3% of spread and combination trades. However, because ratio spreads tend to be larger than most trades, they account for 13.4% of the trading volume attributable to large trades and 18.1% of the volume accounted for by spreads and combinations. Among spreads and combinations, only straddles account for more volume. Moreover, over the sample period, ratio spread trading increased. They accounted for only 8.55% of trading volume in the 1994-95 half of our sample but 18.23% in the 1999-2000 half. In the latter sub-sample, the trading volume attributable to ratio spreads exceeded that attributable to any other spread or combination.

*II.3. Basic Attributes.*

Descriptive statistics for the ratio spreads in our sample are reported in Table 1 after eliminating from the sample 1) ratios involving midcurve options (165 observations), 2) spreads accompanied by a simultaneous futures trade (13 observations), and 3) incomplete observations and apparent recording errors (27 observations). We also drop 22 observations where the time to expiration of the options is less than two weeks since some of our later calculations are impractical for spreads this short. This leaves us with a final sample of 741 ratio spreads. As shown in Table 1, frontspreads, that is ratio spreads in which more options are sold than bought so that possible losses are unbounded while possible gains are bounded (as illustrated in Figures 1a and 1c), are much more common than backspreads (Figures 1b and 1d). Specifically 74.7% are frontspreads. Possible reasons are discussed below. Net purchases are considerably more common than sales; in 72.6% the spread is a debit spread - that is a cash netflow. Put spreads slightly outnumber call spreads 52.2% to 47.8%.

Recall that we cannot distinguish between trades that open and close a position. If every position opening trade was matched by a position closing trade, we would observe 50-50 splits between frontspreads and backspreads, and between credit spreads and debit spreads. The fact that almost three quarters are frontspreads and over 70% are debit spreads has three implications. One, our sample is apparently dominated by position opening trades. Data from our studies of vertical and volatility spreads also indicates this. Two, to the extent that some observed trades are position closing trades, the figures of 74.7% for frontspreads and 72.6% for debit spreads understate the true proportions for position opening trades. Three, the observed backspreads and credit spreads could be dominated by position closing trades.

The ratio spreads in our sample are sizable; the median size is 1500 contracts while the mean is 2842. Of course this is a conditional mean. The observer's instructions are to record all trades in which the smallest leg is 100 contracts or more so for a 2-to-1 ratio spread the minimum size in order to be included in our sample is 300 contracts. Nonetheless, the size of these trades is impressive. The mean and median times to expiration are 3.41 months and 2.77 months (3.38 months and 2.73 months respectively before eliminating those expiring in less than two weeks). These expirys are roughly in line with averages for most options traded in these markets.

The net price of the observed ratio spreads is quite small. Prices in the Eurodollar options market are quoted in basis points which translates to $25 per basis point per contract. By convention, ratio spread prices are quoted for the smallest possible integer values for each leg. For example, the price of a 1-to-2 ratio spread refers to the cost of a spread involving three contracts - one contract in the smallest leg and two in the larger (throughout this paper we will use the terms "smallest" and "largest" legs to refer to the number of contracts in the two legs). For a 2-to3 ratio spread, the quoted price is for five contracts. For consistency, we calculate prices and Greeks for one unit of the smallest leg, so we calculate the price of the 2-to-3 ratio spread as the price of 1 unit of the smaller leg and 1.5 of the larger. On this basis, the mean ratio spread price in our sample is only 3.61 basis points and the median is only 2.5 basis points. In the Eurodollar options on futures market, each basis point represents $25 so in dollars the mean price is $90.25 and the median $62.50. Since in ratio spreads some options are bought and others sold, small net prices are expected. Nonetheless the mean and median net prices for ratio spreads are considerably below those of other spreads such as butterflies and vertical spreads in which options are both bought and sold.

By far the most common ratio is 2-to-1, accounting for 91.8% of all ratio spreads followed by 3-to-1 (4.2%) and 1.5-to-1 (2.6%). Reasons for the popularity of the 2-to-1 ratio are explored below. Similarly, the most common gap between the two strike prices is 25 basis points (60.2%) followed by 12.5 basis points (18.8%) and 50 basis points (18.2%). At maturities exceeding three months, all Eurodollar option strikes are in increments of 25 basis points. However, in May 1995 the CME began adding strikes in increments of approximately 12.5 basis points in between those strikes within about 50 basis points of the underlying futures once the time to expiration was three months or less.[5] Since these strikes are added after open interest is already high in the existing strikes, they tend to be less liquid than the existing strikes. In a majority of cases, therefore, it appears that ratio spread traders are choosing the minimum feasible gap. Again possible reasons for this preference are explored below.

## III. Analysis

*III.1. Descriptions of Ratio Spreads in the Literature*

Our primary interest is how ratio spreads are designed and what this reveals about the objectives of ratio traders. As noted above, ratio spreads receive little attention in most derivatives texts. In practitioner materials (and when discussed in textbooks), ratio spreads are generally described as volatility trades with frontspreads designed to profit from low actual volatility and/or declines in implied volatility and backspreads intended to profit from high volatility and/or increases in implied volatility. Implications of this argument are that the spread's gamma and vega should be the same sign as the larger leg and that the spreads should be designed so that gamma and vega are relatively large.

There is a difference of opinion however as to whether ratio spreads are designed to be delta neutral or whether they are purposefully directional. Based on the profit patterns in Figure 1, the simpler descriptions of ratio spread state that they are appropriate for a speculator when a small movement in the direction of the smaller leg is expected, but not a large movement. However, both Natenberg (1994) and McMillan (1980) describe ratio spreads as "delta neutral" volatility spreads and the CBOT (2002) describes ratio spreads as volatility spreads indifferent to the direction of any future price change. Others imply that ratio spreads are intended as both volatility and directional trades. For instance, Natenberg (1994), who first describes ratios as delta neutral, later argues that call (put) frontspreads are utilized when the trader thinks volatility will be low but is more concerned about being wrong on the down (up) side. According to him, call (put) backspreads are utilized when high volatility is foreseen but particularly on the up (down) side.

As explained by McDonald (2003), ratio spreads can be used to construct a "paylater hedge" which implies the trader should desire a sizable delta on the spread. Suppose a financial institution wishes to hedge against a fall in LIBOR rates below 5%. One possibility is to buy a LIBOR put with 5% strikes but this entails an up-front cost. An alternative is to sell a LIBOR put with a higher strike (say 5.5%) and buy two with strike = 5%. If the price of the higher strike put is double or more the price of the lower strike put, the hedge costs nothing up front. The "cost" is that if LIBOR falls slightly, but not below 5%, the hedger loses on both his original position and the ratio hedge. The implication would be that ratio spreads are designed with low net cost and sizable deltas whose sign is determined by the smaller leg.

Low or zero net cost is an oft mentioned advantage of ratio spreads (e.g., McMillan, 1980, 1996) - usually in the context of descriptions of vertical spreads as instruments for directional speculation. If one wishes to speculate on an increase in interest rates one could buy a LIBOR call but this is costly. The cost can be reduced but not eliminated with a bull spread in which one buys a low strike calls and sells a high strike call. The cost can be further reduced or eliminated with a call frontspread in which one buys a low strike call and sells more than one high strike calls. If this is the spread trader's objective, we should observe ratio spreads with low or zero net cost and sizable deltas whose sign is determined by the smaller leg.

Finally, ratio spreads are sometimes described as trades designed to profit from perceived relative mispricings rather than as bets on how the underlying asset's price will change or its volatility. For instance, Chance (2001) and McMillan (1996) describe a ratio spread as a trade in which the trader buys a options regarded as underpriced and sells those regarded as overpriced. Chance (2001) adds that the ratio of bought to sold options is set to make the position delta neutral.

*III.2. Spread Greeks.*

These characterizations of ratio spreads lead to hypotheses about their Greeks, specifically delta, gamma, and vega. Like its price, a spread's "Greeks" are simple linear combinations of the derivatives for each of its legs, that is, $\mathbf{G_c} = \sum_{i=1}^{I} \mathbf{m_i G_i}$ where $G_i$ is the Greek (delta, gamma, vega, theta, or rho) for leg i and $m_c$ is the number of options bought (+) or sold (-). In a call (put) frontspread, $m_i$ =+1 for the leg with the lower (higher) strike and $m_i$ <-1 [usually -2] for the other leg. In a call (put) backspread $m_i$ = -1 for the leg with the lower (higher) strike and $m_i$ > 1 [usually +2] for the other leg. The smaller leg in terms of absolute m always has a higher price and higher absolute delta. Gamma, vega, and theta are highest on the leg which is closest to the money.[6]

*III.3. Hypotheses.*

While descriptions of ratio spreads in the literature are quite general, they logically lead to several testable hypotheses about ratio spread construction which we now develop. The depiction of ratio spreads as volatility spreads implies:

**H1: Frontspreads are designed with negative gammas and vegas and backspreads with positive gammas and vegas**. As noted above, most of the literature regards ratio spreads as volatility trades with frontspreads described as short volatility positions and backspreads as long volatility positions. This implies that frontspreads (backspreads) should be designed so that they have negative (positive) gammas and/or vegas. In frontspreads (backspreads) more options are sold (bought) than bought (sold), so that gamma and vega should normally be negative (positive) as their characterization in the literature implies. However, this will not be the case if gamma and/or vega are much larger for the smaller leg.

The characterization of ratio spreads as volatility spreads leads to two more specific hypotheses about spread construction:

**H2: Ratio spread trades will chose designs which maximize vega and/or gamma in absolute terms.** If ratio spreads are intended as volatility spreads, large gammas and vegas are obviously desirable. However, since options are both bought and sold, gamma and vega for a ratio spread will normally be less than those for such volatility spreads as straddles and strangles. So if traders sought to maximize gamma and/or vega absolutely, they would abandon ratio spreads altogether. An answer for why they might use ratio spreads instead of straddles or strangles could involve the net price and margin requirements. A short straddle would entail a sizable cash inflow and large margin requirements. The trader can lower the margin requirement considerably with a debit frontspread. This could explain what we observe primarily frontspreads and debit spreads.

One specific implication of the general hypothesis that ratio spread traders seek to maximize gamma and vega is:

**H3: Ratio spreads are constructed with close-to-the-money strikes for the largest legs (in terms of number of contracts) and in-the-money strikes for the smallest leg.** On individual options, gamma and vega are largest for close-to-the money options.[7] Hence, vega and gamma are maximized by choosing close to the money strikes for the larger leg. Since the smaller leg's strike is lower for calls and higher for puts, it should be in-the-money.

While maximizing vega and gamma implies this strike choice, for frontspreads, it is also implied by an objective of maximizing the payoffs at maturity if the LIBOR rate is unchanged. Consider the call frontspread in Figure 1a. The highest payout and profit at expiration occur if the final price of the underlying asset equals the strike of the sold options. At this price, the bought options finish in the money and receive a payout equal to the differential between the two strikes while the sold options expire worthless. The analysis is the same for put frontspreads. Consequently, if the description of frontspreads as spreads designed to profit if volatility is low is correct, frontspread traders should choose strikes so that the strike of the sold options is close to the current asset price meaning that the bought strike is in-the-money.

Use of ratio spreads to construct pay-later hedges implies a different strike choice:

**H4: Ratio spreads are constructed with out-of-the-money strikes for the larger leg.** Consider for example a 2x1 pay later hedge by a hedger who wishes to hedge against a fall in LIBOR rates below z%. He would buy two out-of-the-money LIBOR puts with strike=z and offset their cost by selling one LIBOR put with a higher strike. In most illustrations of pay-later hedges, both strikes are OTM but this is only necessary for the larger strike.

Note that according to H3 at least one leg is ITM and according to H4 at least one leg is OTM. Spreads with one leg OTM and one ITM would be consistent with both but both legs OTM would be inconsistent with H3 and both legs ITM would be inconsistent with H4. As we shall see below, minimization of the net price implies at least one let out-of-the-money.

**H5: In ratio spreads, the implied standard deviation of the sold options will tend to exceed that of the bought options.** This is an implication of the view that ratio trades are used to trade on perceived mispricings. As noted above, Chance (2001) and McMillan (1996) maintain that ratio traders buy options that they regard as underpriced and sell those they regard as overpriced. If so and if these mispricings are reflected in the implied standard deviations, then they should buy options with low implied volatilities and sell those with high implied volatilities.

**H6: Ratio spreads are delta neutral.** As noted above, many writers describe ratio spreads as "delta neutral' while others view them as purposefully directional. Consequently we test the delta neutral hypothesis. As we shall see below, the strikes at which the absolute delta is minimized are usually not those at which gamma and vega are maximized (H2)

**H7: Ratio spreads are designed so that the net price is small.** Some writers, e.g., McMillan (1980, 1996) argue that an advantage of ratio spreads vis-a-vis other volatility spreads, such as straddles and strangles, is that since some options are bought and some sold, they can be designed so that the net price is close to zero. This argument seems to implicitly assume that the spread is a debit spread, since the trader should only care about the net price if she is on the receiving end. On the other hand, there may be an advantage to lowering the net price of credit spreads since margin requirements may be lowered as well.

**H8: Backspreads are designed as credit spreads**. This represents a extension of the argument in H7 combined with the hypothesis that ratio spreads are volatility spreads . In a credit (debit) spread, the price of the sold (purchased) options exceeds that of the purchased (sold) options so that the trader receives (pays) a net cash inflow (outflow). Long straddles and strangles are costly debit spreads since the trader buys both options. In a ratio backspread, more options are bought than sold but the individual prices of the sold options exceeds that of the bought options so the spread can be designed so that the cost of the sold options exceeds that of the bought options resulting in a cash inflow. Consequently, if a trader wishes to long volatility at little cost she should use a ratio backspread designed as a credit spread. According to Natenberg (1994) and McMillan (1980), backspreads are normally designed as credit spreads for this reason.

**H9: Backspreads are designed with positive or small negative thetas.** For completeness, we include and test this hypothesis from the literature though we question the reasoning behind it. Long straddles and strangles have sizable negative thetas.[8] Hence, if the anticipated high volatility (or increase in implied volatility) does not materialize, a long straddle or strangle position loses value. A supposed advantage of a ratio spread versus these other volatility spreads is that it can be designed so that theta is small or even positive. The problem we see with this reasoning is that for options with moderate times to expiration, a ratio spread's theta is close to proportional (but with the opposite sign) to its gamma and vega so if theta is positive, the spreads gamma and vega are normally negative so it is no longer a long volatility position.

## IV. Initial Results

Results are presented in stages. In this section we document characteristics of ratio spreads and explore what they imply for the hypotheses in the previous section. Later we compare the characteristics of the chosen spreads with other possible spreads the trader could have made - that is we consider compare characteristics of the chosen spread with what the characteristics would have been if the trader had chosen a different ratio or different strikes.

Several of our hypotheses concern the spread's Greeks and to estimate these we need the price of the underlying LIBOR futures at the time of the spread trade. Unfortunately, our data set includes neither the LIBOR futures price at the time of the trade nor the exact time of the trade (which would allow us to find the price at that time). Our data also includes only the net price of each spread while we need prices for each leg in order to calculate the Greeks. Consequently, we approximate these prices using an average of the settlement prices on the day of the trade and the preceding day.[9] Greeks were calculated using both the Black (1976) model for options on futures and (since these are American options) the Barone-Adesi Whaley (1987) model.[10] Since the figures are almost identical, only the former is reported in Table 2. As noted above, the vast majority of ratio spreads are in a 1x2 ratio and in most the gap between the strikes is 25 basis points. In order to focus on a more homogeneous sample, statistics for this subset are reported in Table 3.

### *IV.1. Results: H1 and H2*

As hypothesized in H1, Gamma is generally negative for frontspreads (specifically 74.0% ) and positive for backspreads (85.1%). Vega figures are similar. Keeping in mind that some of our observed trades are likely trades which close positions which were opened earlier when the underlying asset price (and hence gamma and vega) were different, the percentages for opening trades are likely even higher.

Our main evidence on whether traders choose designs which maximize vega and/or gamma is provided below where we compare gamma and vega for the actual spread with what these measures would have been for alternative designs. However, Tables 2 and 3 provide initial evidence. Since gamma and vega vary with the term to maturity of the options, it is helpful to examine a measure which controls for expiry instead of gamma and vega directly. For the same term-to-maturity, gamma and vega are both proportional to $n(d) = l\,n(d_l) - h\,n(d_h)$ where l and h are the number of contracts at the low and high strikes respectively (which are negative for contracts shorted), n is the normal density, $d_i = [\ln(F/X_i) + (.5\sigma^2 t)]/\sigma\sqrt{t}$ where i= l or h, $X_l$ is the low strike and $X_h$ the high strike. For a single option, $n(d_i)$ is maximized at .3989 at a strike $X_i = F{*}\exp(.5\sigma^2 t)$ which for the values of normal values of σ and t in our sample is a strike just slightly above F. Hence for a 2x1 ratio spread, the maximum n(d) would be .7979 for a spread where the larger leg (in number of contracts) is approximately at the money and the smaller is far in-the-money.[11] In Table 3, the average n(d) is .2330 which corresponds to that on a single moderately in-or-out-of-the-money option. Except for call backspreads, it does not appear that ratio spread traders are choosing designs which result in very high gammas and vegas.

*IV.2. Results: H3 and H4*

According to H3, if ratio spread traders are designing their spreads to achieve high absolute gammas and vegas, at least one leg should be in-the- money while according to H4 if they are constructing pay-later hedges, at least one leg should be out-of-the-money. As shown in Tables 2 and 3, the data are more consistent with H4. In 68.4% of the observed ratio spreads both strikes are OTM. Despite the characterization of ratio spreads as volatility spreads, most traders do not seem to be choosing designs which maximize gamma and vega. Interestingly, in over 60% of call backspreads at least one strike is ITM, so a comparison of gamma and vega on call backspreads with the other three categories provides an indicator of how much the strike choice matters. On call backspreads, the mean absolute n(d), our measure of gamma and vega which controls for expiry differences, is .6101. For the other three types the maximum n(d) is only .2204.

To this point we have focused on what the characterization of ratio spreads as volatility spreads implies about their gamma and vega, i.e., their short-run characteristics. Another approach would be to look at their long-run characteristics, that is the profits if the positions are held to maturity. In the literature, frontspreads (backspreads) are characterized as bets that volatility will be low (high). From a long-run perspective, this implies that frontspreads (backspreads) should be profitable at expiry if the underlying asset price changes very little (a lot). However, we have seen that most frontspreads are constructed with out-of-the-money strikes and most are debit spreads (initial cash outflow) so it appears that most are unprofitable if the underlying asset price does not change. As shown in Table 2, this is the case - only 36.2% of call frontspreads and 17.9% of put frontspreads are profitable if the LIBOR rate is unchanged at expiration. If indeed frontspreads are bets that actual volatility will be low, they must be bets on volatility in the short-run not over the time to expiration. Moreover, 58.5% of put backspreads are profitable if LIBOR is unchanged while these are characterized in the literature as bets on high future volatility.

In summary, the signs of gamma and vega for frontspreads and backspreads are consistent with their characterization as bets on low or declining and high or increasing volatility respectively. However, beyond that most evidence is inconsistent with this characterization. The chosen strikes result in low gamma and vegas and most frontspreads are unprofitable at expiration if the underlying asset price is unchanged.

*IV.3. Results: H5*

If ratio spreads are not volatility spreads, what is their purpose? One possibility expressed in H5 is that (as described in Chance (2001)), they are used to speculate on apparent mispricings, i.e., that the ratio spread trader buys options regarded as underpriced and sells those regarded as overpriced. If so and if these relative mispricings are reflected in their implied volatilities, then we should observe traders buying options with low implied volatilities and selling options with higher volatilities as hypothesized in H3.

This hypothesis could explain why most frontspreads are constructed with out-of-the-money strikes even though gamma and vega are low for this construction. As shown in Figure 2, implied volatilities are normally lowest for close-to-the money strikes and higher for far in- or out-of-the-money strikes. In out-of-the-money frontspreads, the ratio spread trader is always buying the closer-to-the-money strike and selling the strike further away so implied volatility is normally lower on the bought options. If constructed using in-the-money strikes, the opposite would be true. So H5 could conceivably explain this construction. By the same reasoning, on backspreads traders should be selling an ITM option and buying close to the money.

In Tables 2 and 3 we report whether the implied standard deviation (ISD) is lower on the bought options than on those sold.[12] In 63.7% it is. However in most backspreads it is not. This would contradict H5 unless most observed backspreads are trades closing frontspreads opened earlier. In addition, however, on frontspreads, the average difference between the ISDs of the bought and sold options is small. In our view the evidence on H5 is inconclusive.

*IV.4. Results H6 and H7*

Better tests of these hypotheses follow below where we compare delta and the net price of the chosen spread design with alternatives but Tables 2 and 3 provide initial evidence.

As noted above and stated in H6, many discussions of ratio spreads describe them as "delta neutral." As reported in Table 2, the average absolute delta is .1123. The median is below .10. Whether this is close enough to zero to warrant the term "delta neutral" is in the eye of the beholder. It is noteworthy that it is somewhat below the average delta on straddles (.156) which universally viewed as volatility trades.

A ratio spread could be made exactly delta neutral by adjusting the ratio of bought to sold options. Indeed, Chance (2001) describes ratio spreads this way - as constructed with a ratio (.903 in his example) so that the spread is exactly delta neutral. Clearly, that does not happen. In the Eurodollar options market, the observed ratio spreads are in fairly even ratios of 1.5, 2, 2.5 , 3, 4, and 5 to 1. We observe no ratios of .903-to1 or 2.2-to-1. We think this strong preference for even ratios is probably due to liquidity considerations. There is a ready market for standard ratio spread configurations (especially 1x2). Recent prices for 1x2 ratio spreads are posted on the exchange floor and quotes are readily available. This would not be the case for ratio spreads with unusual ratios.[13]

According to H7, most ratio spreads are designed so that the net price is small. Our figures are consistent with this - particularly for frontspreads. As reported in Table 2, the net price of ratio spreads is generally quite small averaging only 3.6 basis points. The median is only 2.5 basis points. By comparison other average prices in our data set are: straddles: 63.5 bp, strangles: 26.1 bp, butterflies: 6.5 bp, vertical spreads: 9.2 bp, simple calls: 10.1bp, simple puts: 13.2bp.

As shown in Table 2, the mean net price of frontspreads, 2.92 bp, is considerably lower than that for backspreads, 5.64 bp. The difference is significant at the .001 level. Since frontspreads are normally debit spreads while backspreads are normally credit spreads, this is could be because price is more important to the debit spread trader, who is facing a cash outlay. Also, as explained earlier, it is possible that many of the backspreads are position closing trades. If so, it may be that initially they were designed with very low net prices but the absolute price has changed as LIBOR has changed.

*IV.5. Results: H8 and H9*

According to hypothesis H8, ratio backspreads are normally designed as credit spreads. The rationale is that traders wishing to long volatility but avoid the high cost of long straddles and strangles would turn to backspreads constructed as credit spreads. As shown in Table 2, 82.9% of call backspreads and 86.2% of put backspreads are credit spreads so the data is consistent with this hypothesis. Interestingly, frontspreads are overwhelmingly debit spreads so it is clear that in most ratio spreads the sign of the net price is determined by the smaller leg in terms of number of contracts. The fact that most frontspreads are debit spreads could mean that the preponderance of credit spreads on backspreads is simple the flip side of the frontspread preference is most of the backsrpread trades are closing frontspread positions.

Although we questioned the reasoning behind it we included the hypothesis (H9) from the literature that backspreads are designed with positive or small thetas. As reported in Table 2, the opposite appears to be the case.

*IV.6. Summary*

In summary, the figures presented in Tables 2 and 3 appear is consistent with the hypotheses that ratio spreads are designed so that the net price is small (H7) and that they are approximately delta neutral (H6). Gamma and vega are negative for frontspreads and positive for backspreads (H1), at least one leg is out-of-the-money (H4), and most observed backspreads are credit spreads (H8). The data appear inconsistent with the hypotheses that at least one leg is in-the-money (H3) and that backspreads have negative or small thetas (H9). Results are inconclusive for the remaining hypotheses.

## V. The Spread Ratio

Next we compare characteristics of the chosen designs with possible alternatives that the spread traders could have chosen. By comparing the chosen design with the alternatives, we hope to discern the traders' objectives. Our data set for this analysis consists of the 431 spreads in

Table 3 where the ratio is 1x2 and the gap between the two strikes is 25 basis points. While it would be desirable to examine other ratios and strike differentials, there are not enough observations for a meaningful analysis. We start by considering the ratio choice.

In frontspreads (backspreads) more (fewer) options are sold than bought. So for frontspreads increasing the ratio reduces the net cash inflow, gamma, and vega while these characteristics are increased for backspreads. An increase in the ratio increases delta for call backspreads and put frontspreads and decreases delta for put frontspreads and call backspreads. However, many of our hypotheses concern absolute values of these characteristics and whether the absolute value rises or falls depends on each leg's strike relative the underlying LIBOR futures.

Results are shown in Table 4. In most cases choosing a ratio other than the 1x2 ratio actually chosen would have resulted in an higher absolute net price and higher absolute delta. This holds for both calls and puts and frontspreads and backspreads. Consistent with hypotheses H6 and H7 therefore it appears that ratio spread traders are choosing the ratio which approximately minimizes the net price and delta.

As noted above, most frontspreads are debit spreads (a small net cash out-flow) and most backspreads are credit spreads (net cash inflow). As reflected in panel A in Table 4, if the ratio were 1x1 (in effect a vertical spread), these relations must always hold. As shown in Panel C, in most cases a 1x3 construction would have switched these relations, turning most frontspreads into credit spreads and backspreads into debit spreads. Hence the 1x2 choice is consistent with H8 - that backspreads are designed as credit spreads. From the ratio choice, it also appears that frontspread traders could have a decided preference for debit spreads, i.e., a small net cast outflow.

As shown by the figures for n(d) in Table 4, choosing a 1x1.5 ratio would normally have meant lower absolute gammas and vegas while choosing a 1x3 ratio would have meant higher absolute gammas and vegas. Consequently, the choice of a 1x2 ratio appears inconsistent with

H2 - that ratio spread traders choose designs which maximize vega and/or gamma. If ratio spreads are intended as volatility spreads, they are relatively weak ones in that vega and gamma are normally fairly small and could have been made larger by choosing a higher ratio - albeit at the expense of a higher deltas.

## VI. The Strike Price Decision

Next we examine what the trader's strike price choice reveals about their objectives. Specifically, we compare characteristics of the chosen strikes with estimates of what these strikes would have been if the traders had instead chosen slightly higher or lower strikes holding the gap between the two strikes the same. For instance, if the observed call spread is one in which the ratio spread trader buys one call with a strike, K, of 6.25 and sells two calls with a strike of 6.50, we estimate what the price and Greeks of the spread would have been if he had instead bought one call with K=6.00 and sold two with K=6.25 and we estimate the price and Greeks if he had bought one call with K=6.50 and sold two with K=6.75. Note that for call spreads, the lower strike pair is more in-the-money and for put spreads the higher strike pair is more in-the-money.

### *VI.1. Spread Characteristics and the Strike Price Decision.*

First, consider how this strike choice should impact spread characteristics. To keep the discussion manageable we limit our analysis to call frontspreads in which the trader always longs one call at the lower strike and shorts M>1 at the higher. The extension to the other four types shown in Figure 1 is trivial.

To begin, suppose that the two strikes are both quite low so that both options are deep in-the-money. At this point, the prices of both options will be close to their intrinsic value so that the spread is a credit spread with a sizable cash inflow - meaning that the net price or cost is a large negative figure. Since both options are deep in-the-money, their deltas are close to 1, so the delta of the position is 1-M, e.g., -1 for M=2. Consequently, as both strikes are raised holding the differential constant, the net price rises (becomes a smaller credit spread).[14] Starting from deep in-the-money, the spread's gamma, vega, and theta are initially close to zero. As the strikes increase, gamma and vega fall (rise in absolute terms) since they are higher for the closer-to-the money option which is sold. Theta rises for the same reason. Since gamma is negative, the spread's delta rises (falls in absolute terms). As the two strikes continue to rise, the net price may become negative (a net outflow or debit spread) and delta may become positive. When both options were in-the-money, gamma, vega, and theta were higher on the sold options but once both are out-of-the-money, gamma, vega, and theta are higher on the bought options so all three fall in absolute terms. It is therefore possible for gamma and vega to become positive and for theta to become negative.

These relationships are illustrated for the median call frontspread in our data set in Figure 3. Specifically, in our data set the median values are: t = 2.83 months, which we round off to 3 months in Figure 3, σ = 11%, and F (the underlying LIBOR futures) = 6.46%, which we round to 6.5%. The ratio is 1x2 and the strike price differential is 25 basis points. The mean of the two strikes is graphed along the X axis and the net price and Greeks along the Y axes where both the Greeks and net price are calculated using the Black (1976) model for options on futures. If the Greeks and prices are calculated using the Barone-Adesi-Whaley (BAW) model for American options, the results are virtually the same except when the options are deep in-the-money. Since all options in a ratio spread have the same time-to-expiration, if implied volatility is the same at both strikes, gamma and vega are proportional to each other and to $n(d) = n(d_l) - M\, n(d_h)$ where n is the normal density, $d_i = [\ln(F/X_i) + (.5\sigma^2 t)]/\sigma\sqrt{t}$, $X_l$ is the low strike and $X_h$ the high strike. So to simplify the graph, we graph n(d) instead of gamma and vega individually.

As explained above, when the mean strike is very low, delta ≈ -1, gamma. vega, and theta ≈ 0 and the net price is sizable and negative. When the two strikes straddle the underlying LIBOR futures value, vega and gamma are sizable and negative and theta is sizable and positive, the net price is small and delta is small but negative. When both strikes are out-of-the-money, all the Greeks have small absolute values. Over part of this range gamma, vega, and delta become positive and theta negative though the values are small. In the figure we also graph the profit if the spread is held to expiration and the final LIBOR value is 6.5%. The maximum occurs when the bought call is at-the-money and the two sold calls out-of-the-money.

In Figures 4 and 5, we repeat the graphs for ratio spreads with times to expiration of 1.5 months and 6 months respectively. As shown in Figure 5, when the time-to-expiration is long (or volatility high), the Greeks may never switch signs to a significant degree. As illustrated in Figure 4, when the time-to-expiration is short (or volatility low), gamma, vega, and delta may take large positive values over part of their range.

Figures 3-5 shed light on the interpretation of frontspreads and backspreads. As noted above, frontspreads are viewed in the literature as short volatility positions and backspreads as long volatility positions. However, as shown in Figures 3 and 5, it is possible to construct frontspreads with small positive gammas and vegas (that is long volatility positions) by choosing out-of-the-money strikes. By increasing the strike price differential from the 25 basis points in the Figures or lowering the ratio, these positive values can be increased. Nonetheless it is clear that for reasonable parameter values, if a ratio trader seeks a position with sizable negative gammas and/or vegas, they should choose a frontspread with at-the-money or just in-the-money strikes. If they desire sizable positive gammas and vegas, they should choose a backspread.

*VI.2. Results*

Next we compare characteristics of the chosen spreads with the characteristics of spreads at slightly higher and lower strikes. By examining the traders' choices among the available strikes, we hope to discern their objectives. As before the sample consists of the 431 spreads with a 25 basis point differential in a 1x2 ratio. Most strikes in the Eurodollar market are in increments of 25 basis points. However, in May 1995, the Exchange started adding close-to-the-money strikes in increments of about 12.5 basis points when there are less than three months to expiration. Since added later, trading in these is light particularly in the first few weeks so they are less liquid. If (as was normally the case) neither strike was at one of these in-between strikes, we chose the strike pair 25 basis points lower and the pair 25 basis points lower than the chosen pair for our comparison. That is we continued to avoid the in-between strikes. If one of the strikes was an in-between strike, we used strike pairs 12.5 basis points higher and lower.

Results of this experiment are shown in Table 5. As observed above, in most ratio spreads both strikes are out-of-the-money. Hence, as documented in Table 5, for most spreads choosing slightly further out-of-the-money strikes (higher for calls and lower for puts) leads to lower absolute values for delta, gamma, vega, and the net price. Reducing the strikes on call spreads or increasing the strikes on put spreads generally raises delta, gamma, vega, and the net price in absolute terms.

To this point most of our evidence has been consistent with the hypothesis (H6) that ratio spread traders design their trades to minimize the absolute delta. However, it is apparent from Table 5 that for most traders this is not an overriding objective since delta could be reduced further by choosing further out-of-the-money strikes. Of course as illustrated in Table 5, choosing further out-of-the-money strikes to minimize delta would normally also reduce the absolute gamma and vega which would clearly be undesirable if these are indeed volatility spreads. It is also clear that the traders do not design the spreads to maximize gamma and vega as hypothesized in H2 since in most cases this could have been achieved by choosing more in-the-money strikes (which in turn would have entailed higher deltas).

Much of our evidence to this point has been consistent with the hypothesis (H7) that ratio spread traders seek designs which result in low net prices and also indicates that frontspread traders prefer debit spreads. It is clear from Table 5, however, that neither of these is a absolute priority since most could have reduced the net price even more by choosing further out-of-the-money strikes. Of course, as just noted, choosing further out-of-the-money strikes to achieve this possible objective would lower gamma and vega which would be undesirable if these are indeed volatility spreads.

## VII. Conclusions

After this research there is much we now know about ratio spreads but much about the traders objectives remains unclear. Among our findings are these. One, ratio spreads are actively traded. In the market we observe they are second only to straddles in volume accounting for over 13% of trading volume. Two, at least three-quarters are frontspread which means that potential profits are bounded and potential losses unbounded and generally means that gamma and vega are negative. Three, most frontspreads are debit spreads (net initial cash outflow) and most backspreads are credit spreads. Four, over 90% use a 1x2 ratio and in most the difference between the two strikes is the smallest possible. Five, the net price is quite low; the lowest among all combinations we study. Six, most spreads are approximately but not completely delta neutral. Seven, gamma and vega are generally negative for credit spreads and positive for backspreads but their absolute values are small compared to other volatility spreads. Eight, related to several of these observations, most are constructed with out-of-the-money strikes. This tends to result in relatively small net prices and deltas but smaller gamma and vegas compared to at-the-money strikes. It also means that if the underlying asset price does not change, most frontspreads lose money - which conflicts with the portrayal of frontspreads as designed to profit from low volatility.

As discussed several different uses and objectives for ratio spreads have been proposed in the literature. No one stands out from our data. It appears that either the objective varies from trader to trader or that individual traders have several objectives. The mean and median gamma and vega are small relative to such volatility spreads as straddles and strangles and could be increased by switching to close-to-the-money strikes. The mean and median delta seem low if the objective is to constrict a pay-later-hedge. We now know quite a bit about how ratio spreads are constructed but exactly why remains somewhat unclear.

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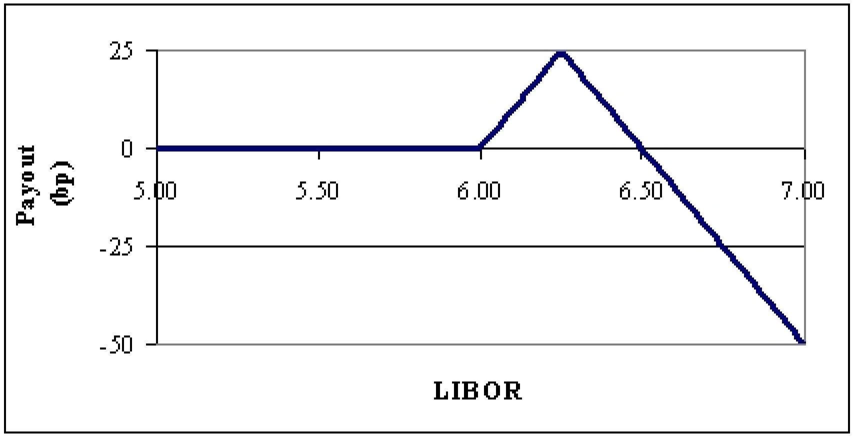
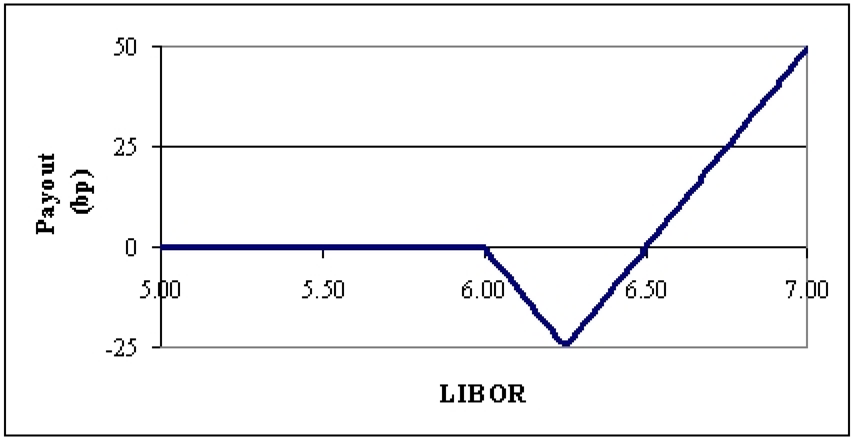
**Figure 1 - Payoff Diagrams for Ratio Spreads**

Payouts on Eurodollar call and put 1x2 ratio spreads at expiration are graphed as a function of the LIBOR rate (the underlying asset) at expiration. For the call spreads the lower strike is 6.00% and the higher is 6.25% and on put spreads the lower strike is 5.75% and the higher 6.00%.

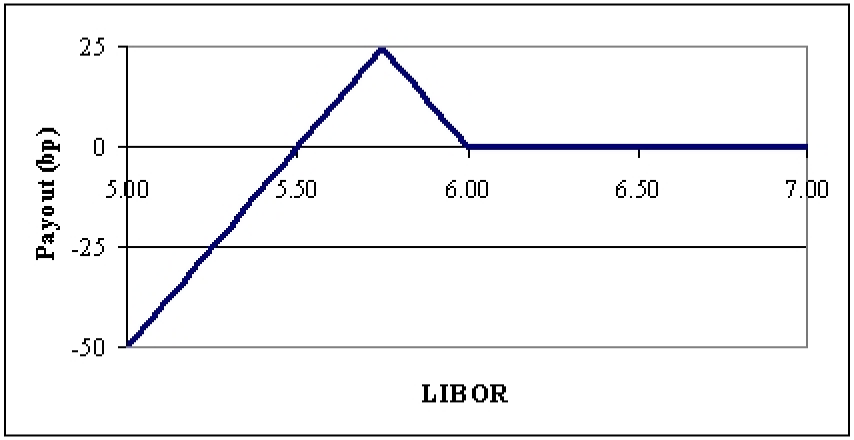
**Panel A: Call Frontspread**



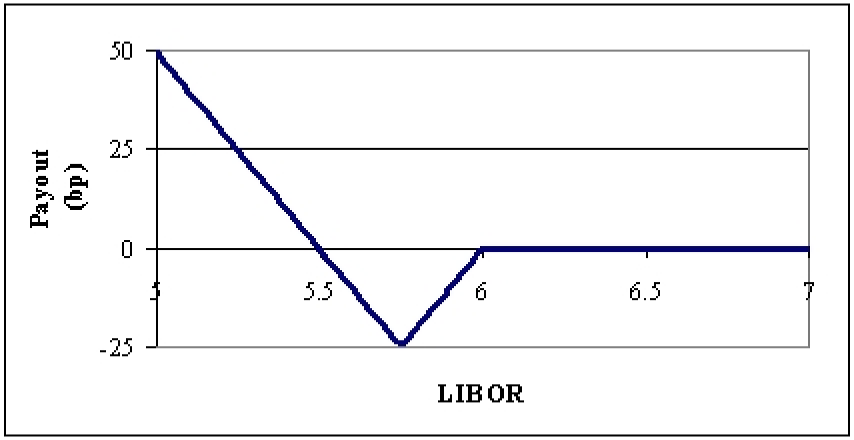

**Panel B: Call Backspread**




**Panel C: Put Frontspread**




**Panel D: Put Backspread**



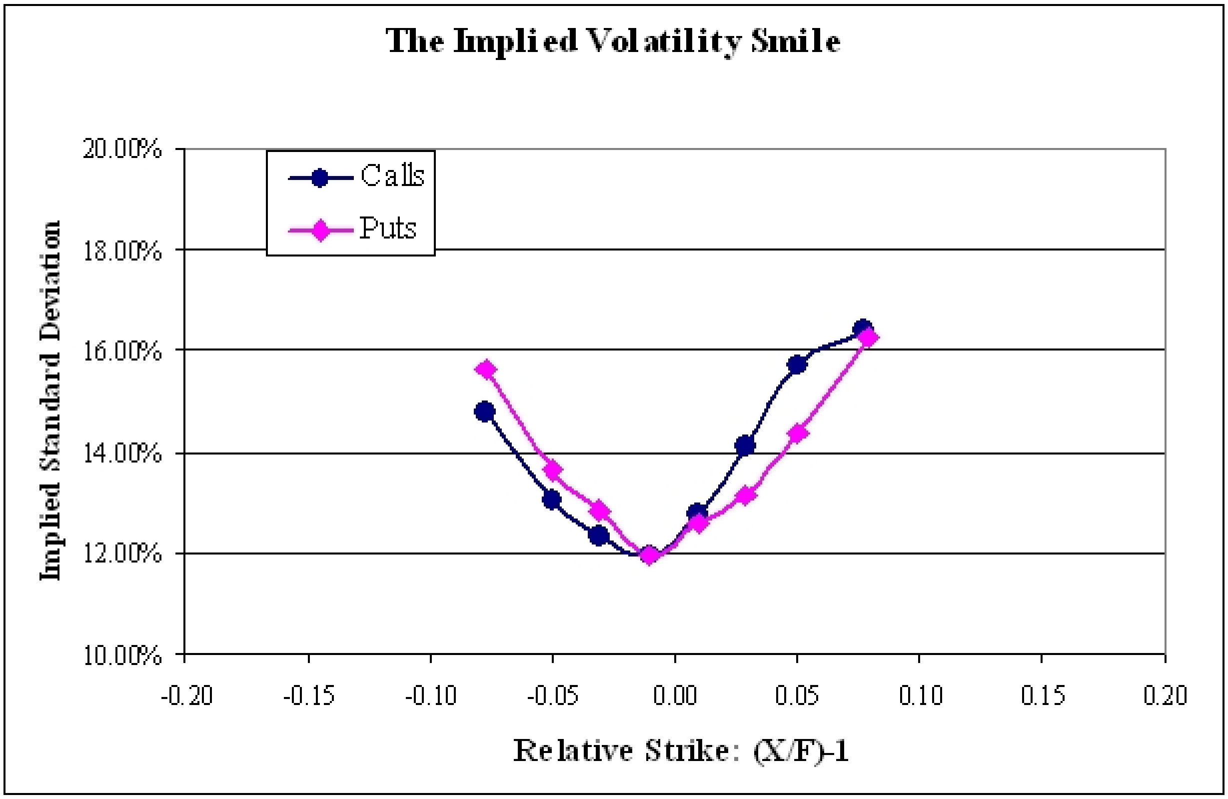
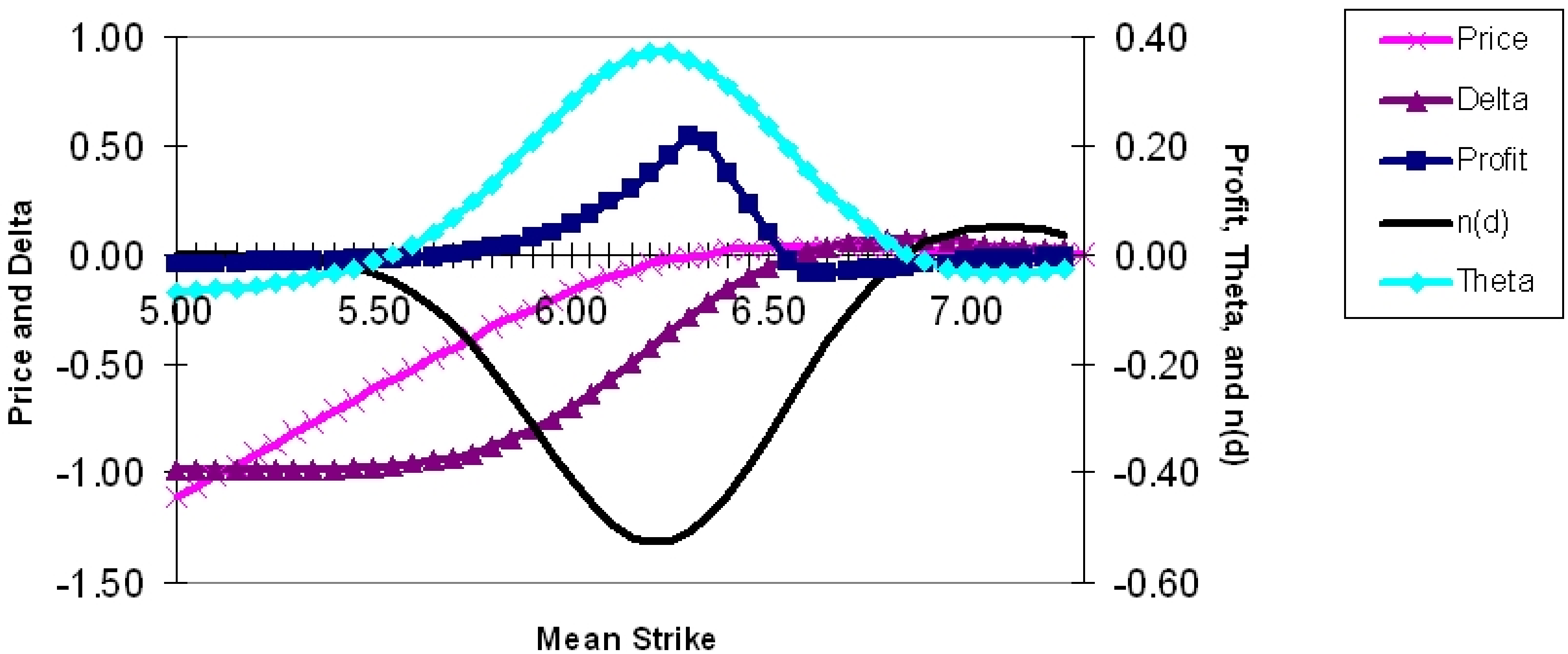



**Figure 2 - The Implied Volatility Smile.** Mean implied standard deviations at various strike prices are reported based on daily data for the periods 5/10/94-5/18/95 and 4/18/99-7/31/00. The implied volatilities are those calculated by the CME from option and futures settlement prices for options maturing in 2 to 4 weeks. Strike prices are expressed in relative terms as (X/F)-1 where X is the strike price (in basis points) and F is the underlying futures price (in basis points).

## Figure 3 Ratio Spread Characteristics as Function of the Mean Strike for Expiry=3months LIBOR=6.5% and Volatility=11%



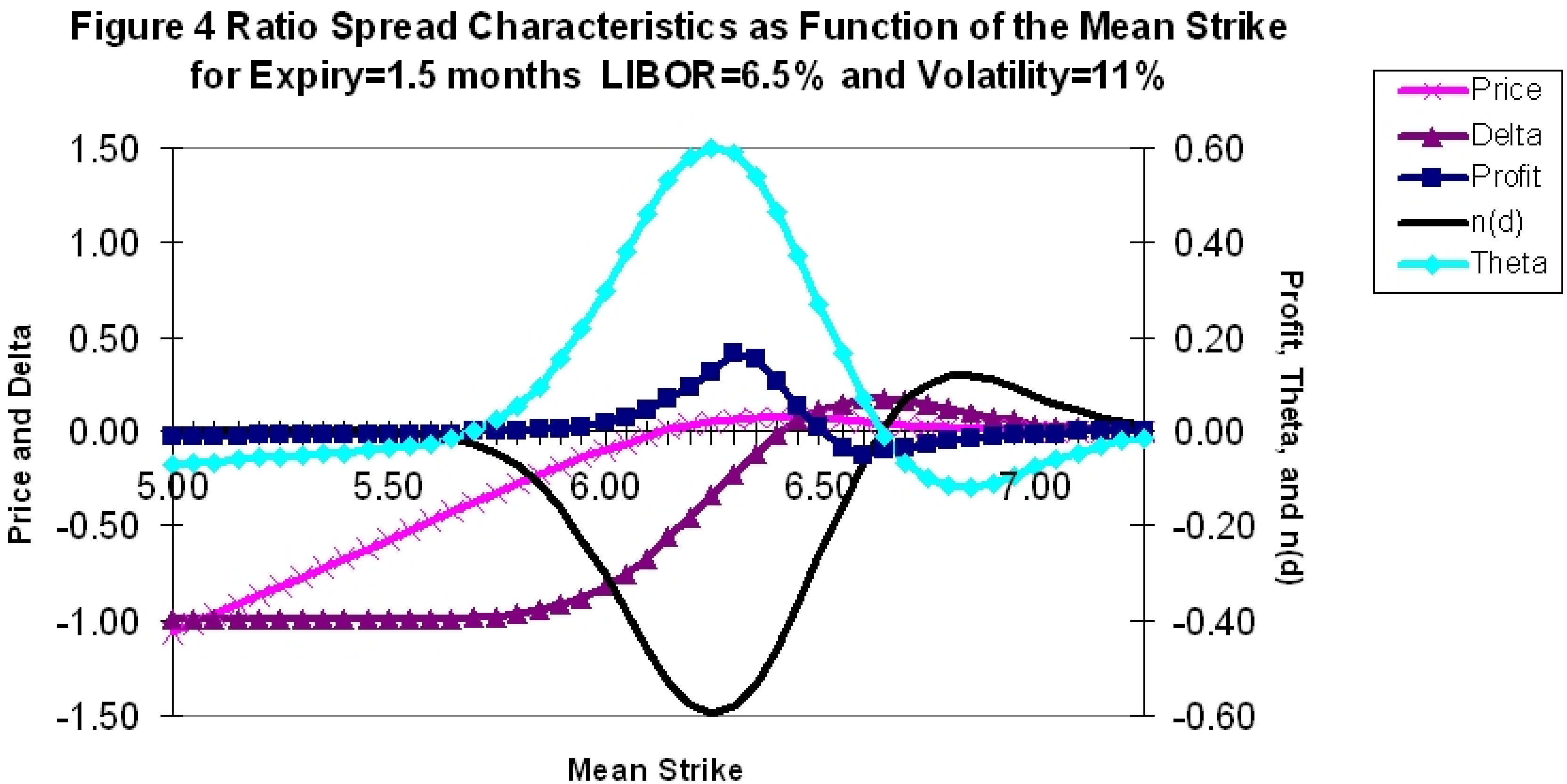


Figure 4 Ratio Spread Characteristics as Function of the Mean Strike
for Expiry=1.5 months LIBOR=6.5% and Volatility=11%
Price
Delta
Profit
n(d)
Theta
1.50
1.00
0.50
0.00
-0.50
-1.00
-1.50
0.60
0.40
0.20
0.00
-0.20
-0.40
-0.60
5.00
5.50
6.00
6.50
7.00
Price and Delta
Profit, Theta, and n(d)
Mean Strike

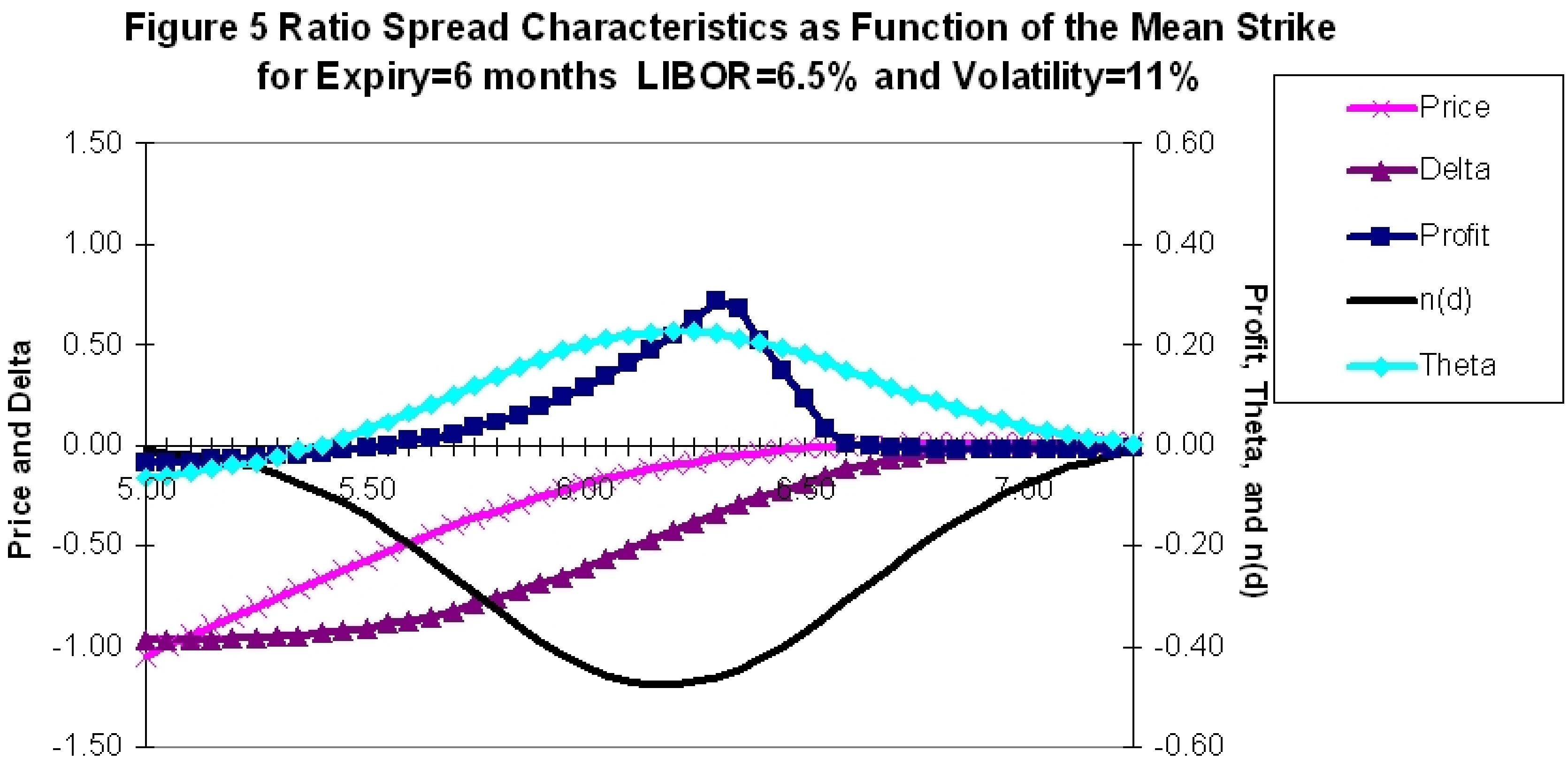


Figure 5 Ratio Spread Characteristics as Function of the Mean Strike
for Expiry=6 months LIBOR=6.5% and Volatility=11%
Price
Delta
Profit
n(d)
Theta
Price and Delta
Profit, Theta, and n(d)
1.50
1.00
0.50
0.00
-0.50
-1.00
-1.50
0.60
0.40
0.20
0.00
-0.20
-0.40
-0.60
5.00
5.50
6.00
6.50
7.00

**Table 1 - Descriptive Statistics**

Various descriptive statistics are presented based on a sample of 741 large ratio spreads observed in the Eurodollar options market on 385 trading days over three periods: (1) 5/12/1994-5/18/1995, (2) 4/19/1999-9/21/1999, and (3) 3/17/2000-7/31/2000.

**Panel A - Descriptive Statistics**

| Variable | Mean | Median | Std. Dev. | |
|---|---|---|---|---|
| Size (in contracts) | 2842 | 1500 | 3572 | |
| Time to expiration (months) | 3.41 | 2.77 | 2.48 | |
| Price (in basis points) | 3.61 | 2.50 | 4.72 | |

**Panel B - Spread Types**

| Spread Type | Call Frontspread | Call Backspread | Put Frontspread | Put Backspread |
|---|---|---|---|---|
| Percentage | 34.7% | 12.7% | 40.00% | 12.7% |

**Panel C - Ratios - percentages**

| 1.5 | 2 | 2.5 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| 2.56% | 91.77% | 0.27% | 4.18% | 0.94% | 0.27% |

**Panel D - Strike Price Gaps (in basis points) - Percentages**

| 12 or 13 bp | 25 bp | 37 or 38 bp | 50 bp | 75bp | 100bp |
|---|---|---|---|---|---|
| 18.8% | 60.2% | 0.4% | 18.2.9% | 0.8% | 1.6% |

**Table 2 - Ratio Spread Characteristics - Full Sample**

Characteristics of 741 ratio spreads are reported. Greeks and implied standard deviations are based on an average option and futures settlement prices on the day of the trade and the previous day.

| | All | Call Front Spread | Call Back Spread | Put Front Spread | Put Back Spread |
|---|---|---|---|---|---|
| Mean Net Price (basis points) | .58 | 2.30 | -5.82 | 2.67 | -4.35 |
| Mean Absolute Net Price (bp) | 3.61 | 2.98 | 6.58 | 2.86 | 4.71 |
| Median Absolute Net Price (bp) | 2.50 | 2.00 | 4.50 | 2.00 | 3.00 |
| Percent Credit Spread | 27.40% | 12.45% | 82.98% | 4.05% | 86.17% |
| Mean Delta | -.0143 | .0004 | .0043 | -.0357 | -.0057 |
| Mean Absolute Delta | .1123 | .1062 | .1543 | .0971 | .1348 |
| Mean Gamma | -.0878 | -.4927 | .8730 | -.2630 | .6082 |
| Percent Positive Gamma | 41.03% | 18.68% | 91.49% | 32.43% | 78.72% |
| Mean Vega | -.1832 | -.6753 | .8945 | -.3604 | .6429 |
| Percent Positive Vega | 37.38% | 13.23% | 93.62% | 27.04% | 79.79% |
| Mean absolute n(d) | .2354 | .2145 | .6101 | .1394 | .2204 |
| Mean Theta | .0488 | .1776 | -.2486 | .1003 | -.1678 |
| Percent Positive Theta | 66.26% | 92.22% | 5.32% | 78.72% | 17.05% |
| Percent Out-of-money Strikes | 68.42% | 66.15% | 39.36% | 82.09% | 60.64% |
| Percent In-the-money Strikes | 4.72% | 3.89% | 7.45% | 2.36% | 11.70% |
| Percent Strikes Straddle Futures | 26.86% | 29.96% | 53.19% | 15.54% | 27.66% |
| Mean Profit if no Price Change (bp) | .25 | 1.51 | -3.75 | 1.73 | -.04 |
| Percent Profitable if no Price Change | 32.12% | 36.19% | 39.36% | 17.19% | 58.51% |
| Mean ISD difference (sold-bought) | .49% | .88% | -.46% | .57% | .17% |
| Percent ISD(sold)>ISD(bought) | 63.72% | 90.27% | 15.96% | 64.19% | 53.19% |
| Observations | 741 | 257 | 94 | 296 | 94 |

**Table 3 - Ratio Spread Characteristics - Restricted Sample**

Characteristics of 413 2x1 ratio spreads with a 25 basis point differential between the two strikes are reported. Greeks and implied standard deviations are based on an average option and futures settlement prices on the day of the trade and the previous day.

| | All | Call Front Spread | Call Back Spread | Put Front Spread | Put Back Spread |
|---|---|---|---|---|---|
| Mean Net Price (basis points) | 0.84 | 1.68 | -3.33 | 2.62 | -3.59 |
| Mean Absolute Net Price (bp) | 3.15 | 2.53 | 4.70 | 2.87 | 4.10 |
| Median Absolute Net price (bp) | 3.00 | 2.00 | 4.50 | 3.00 | 3.00 |
| Percent Credit Spread | 26.88% | 15.57% | 74.51% | 5.82% | 84.31% |
| Mean Delta | -.0189 | -.0132 | .0292 | -.0377 | -.0107 |
| Mean Absolute Delta | .1174 | .1188 | .1722 | .0972 | .1338 |
| Mean Gamma | -.0014 | -.4844 | 1.0784 | -.1870 | .7623 |
| Percent Positive Gamma | 42.37% | 17.12% | 94.12% | 32.80% | 86.27% |
| Mean Vega | -.1713 | -.6874 | .8977 | -.3347 | .6001 |
| Percent Positive Vega | 40.44% | 16.39% | 89.77% | 29.40% | 86.27% |
| Mean absolute n(d) | .1959 | .2320 | .3257 | .1322 | .2164 |
| Mean Theta | .0467 | .1954 | -.2798 | .0989 | -.1756 |
| Percent Positive Theta | 63.68% | 90.98% | 5.88% | 76.72% | 7.84% |
| Percent Out-of-money Strikes | 66.83% | 61.48% | 23.53% | 83.60% | 60.78% |
| Percent In-the-money Strikes | 5.33% | 4.92% | 9.80% | 2.12% | 13.73% |
| Percent Strikes Straddle Futures | 27.85% | 33.61% | 66.67% | 14.29% | 25.49% |
| Mean Profit if no Price Change (bp) | 0.13 | 2.36 | -6.08% | 1.27% | -3.22% |
| Percent Profitable if no Price Change | 30.99% | 43.44% | 21.57% | 16.93% | 62.75% |
| Mean ISD difference (sold-bought) | .0046 | .0089 | -.0036 | .0041 | .0046 |
| Percent ISD(sold)>ISD(bought) | 63.20% | 89.34% | 19.61% | 59.79% | 56.86% |
| Observations | 413 | 122 | 51 | 189 | 51 |

**Table 4 - Impact of the Chosen Ratio on Spread Characteristics**

For the 431 ratio spreads in our sample for which the ratio was 1-to-2 and the gap between the two strikes was 25 basis points , the price and estimated Greeks at the chosen ratio are compared with estimates of what these characteristics would have been if the trader had chosen a ratio of 1-to-1 (a vertical spread) or 1-to-3. Means of the estimates and the percentage which are credit spreads are reported below. As described in the text, both gamma and vega are proportional to n(d).

| | All | Call Frontsprea d | Call Backsprea d | Put Frontsprea d | Put Backsprea d |
|---|---|---|---|---|---|
| Panel A: 1-to-1 Spreads | | | | | |
| Price (in basis points) | 3.10 | 7.69 | -11.01 | 6.59 | -6.71 |
| Absolute Price | 7.48 | 7.69 | 11.01 | 6.59 | 6.71 |
| Delta | -0.0302 | 0.2328 | -0.2994 | -0.1973 | 0.2288 |
| Absolute Delta | 0.2243 | 0.2328 | 0.2994 | 0.1973 | 0.2288 |
| n(d) | 0.0666 | 0.068 | 0.0065 | 0.1194 | -0.0593 |
| Absolute n(d) | 0.1149 | 0.079 | 0.0902 | 0.1268 | 0.1163 |
| Percent Credit Spreads | 24.70% | 0.00% | 100.00% | 0.00% | 100.0% |
| Panel B: 1-to-2 Spreads - the configuration actually observed | | | | | |
| Price (in basis points) | 0.84 | 1.68 | -3.33 | 2.62 | -3.59 |
| Absolute Price | 3.15 | 2.53 | 4.70 | 2.87 | 4.10 |
| Delta | -0.0189 | -0.0132 | 0.0292 | -0.0377 | -0.0107 |
| Absolute Delta | 0.1174 | 0.1188 | 0.1722 | 0.0972 | 0.1338 |
| n(d) | -0.0450 | -0.2138 | 0.3181 | -0.1018 | 0.2065 |
| Absolute n(d) | 0.1959 | .2320 | 0.3257 | 0.1322 | 0.2164 |
| Percent Credit Spreads | 26.88% | 15.58% | 74.51% | 5.82% | 84.31% |
| Panel C: 1-to-3 Spreads | | | | | |
| Price (in basis points) | -1.21 | -0.44 | 4.08 | -1.56 | 2.35 |
| Absolute Price | 5.03 | 5.68 | 7.05 | 3.75 | 6.18 |
| Delta | -0.008 | -2592 | 0.3578 | 0.1219 | -0.2501 |
| Absolute Delta | 0.2418 | 0.2883 | 0.3855 | 0.1606 | 0.2877 |
| n(d) | -0.1566 | -0.4957 | 0.6426 | -0.3230 | 0.4722 |
| Absolute n(d) | 0.4333 | 0.4977 | 0.6441 | 0.3237 | 0.4744 |
| Percent Credit Spreads | 54.24% | 67.21% | 39.22% | 52.38% | 45.10% |
| Observations | 413 | 122 | 51 | 189 | 51 |

**Table 5 - Impact of the Strike Price Choice on Spread Characteristics**

The price and estimated Greeks for the strike price pair are compared with estimates of what these characteristics would have been if the trader had chosen the next higher or lower strikes holding the ratio and the gap between the two strikes the same. Means of the estimates and the percentage which are credit spreads are reported below. As described in the text, both gamma and vega are proportional to n(d). The sample consists of 431 ratio spreads for which the ratio is 1x2 and the gap between the two strikes is 25 basis points.

| | **All** | **Call Frontsprea d** | **Call Backspread** | **Put Frontsprea d** | **Put Backspread** |
|---|---|---|---|---|---|
| Panel A: Lower Strikes | | | | | |
| Price (in basis points) | 0.34 | -0.43 | 1.06 | 1.43 | -2.61 |
| Absolute Price | 3.18 | 4.81 | 6.02 | 1.50 | 2.66 |
| Delta | -0.0285 | -0.2293 | 0.4065 | -0.0443 | 0.0756 |
| Absolute Delta | 0.1603 | 0.2520 | 0.4102 | 0.0522 | 0.0916 |
| n(d) | -0.0622 | -0.4372 | 0.4841 | 0.0166 | -0.0036 |
| Absolute n(d) | 0.2382 | 0.4390 | 0.4841 | 0.0745 | 0.1183 |
| Percent Credit Spreads | 34.62% | 45.90% | 49.02% | 6.88% | 96.08% |
| Panel B: Actual Strikes | | | | | |
| Price (in basis points) | 0.84 | 1.68 | -3.33 | 2.62 | -3.59 |
| Absolute Price | 3.15 | 2.53 | 4.70 | 2.87 | 4.10 |
| Delta | -0.0189 | -0.0132 | 0.0292 | -0.0377 | -0.0107 |
| Absolute Delta | 0.1174 | 0.1188 | 0.1722 | 0.0972 | 0.1338 |
| n(d) | -0.0450 | -0.2138 | 0.3181 | -0.1018 | 0.2065 |
| Absolute n(d) | 0.1959 | .2320 | 0.3257 | 0.1322 | 0.2164 |
| Percent Credit Spreads | 26.88% | 15.58% | 74.51% | 5.82% | 84.31% |
| Panel C: Higher Strikes | | | | | |
| Price (in basis points) | 0.77 | 1.06 | -2.13 | 1.50 | 0.29 |
| Absolute Price | 3.28 | 1.35 | 2.31 | 4.28 | 5.20 |
| Delta | 0.0191 | 0.0265 | -0.0704 | 0.1200 | -0.2826 |
| Absolute Delta | 0.1335 | 0.0512 | 0.1069 | 0.1503 | 0.2943 |
| n(d) | -0.1273 | -0.0504 | 0.0406 | -0.3533 | 0.3584 |
| Absolute n(d) | 0.2515 | 0.0988 | 0.1321 | 0.3533 | 0.3584 |
| Percent Credit Spreads | 36.08% | 12.30% | 92.20% | 31.22% | 56.86% |
| Observations | 413 | 122 | 51 | 189 | 51 |

ENDNOTES

1. Definitions of ratio spreads and terminology differ in the options literature. Since we are investigating Eurodollar ratio spreads and these are traded on the Chicago Mercantile Exchange, we use their definition.

2. Eurodollar options are quoted as 100-LIBOR in order to make their price behavior analogous to a bond, i.e., when the interest rate rises the price falls..

3. The Futures Industry Institute data does not report implied volatilities for the April 1999 - September 1999 period so these figures are based on 1994-1995 and 2000.

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

5. Initially these in-between strikes were 12 basis points from one existing strike and 13 from the other - not 12.5 from each - but we will treat all as midway between the two.

6. This is an approximation. To be precise, the Black gamma and vega are highest on the leg whose strike is closest to $Fe^{.5\sigma^2 t}$ where F is the underlying futures price, σ is volatility and t is the time to expiration. For our data however the e term is close to 1. For instance using the median values of σ and t, $Fe^{.5\sigma^2 t} = F(1.002)$. Likewise the point at which theta is maximized varies slightly from this.

7. See footnote 6.

8. Theta is sometimes defined as the derivative of the option price with respect to calendar time so that it is negative for single options and sometimes as the derivative of the option price with respect to the time to expiration so that it is positive for single options. We follow the former convention.

9. One check on the appropriateness of these approximations and the accuracy of our data set is to compare the price for our trades with the prices calculated from the settlement prices for the individual legs. The average absolute difference is approximately one basis point. We eliminated five observations where the difference exceeded four basis points.

10. In the Greek calculations, constant maturity 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.

11. Since in ratio spreads the smaller leg is always at a lower strike for calls and higher for puts, it cannot be out-of-the money if the larger is in-the-money.

12. Again we caution that since we only observe the net price of a ratio spread, the ISDs, like the Greeks, are estimated using settlement prices for the options and LIBOR futures so contain measurement error.

13. If a trader wishes to form a ratio spread with an unusual ratio, they might place separate orders for each leg in which case it would appear in our data as two naked option trades, not a

ratio spread. Of course, in this case they cannot set limit prices without running the risk that only half the spread will be executed.

14. This makes use of the approximation that the partial derivative of an option's price with respect to its strike is approximately equal to the negative of its partial derivative with respect to the underlying asset price (its delta).