THE EFFECTS OF HEDGERS AND SPECULATORS ON THE IMPLIED VOLATILITY SKEW: A TRANSACTIONS DATA STUDY

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ABSTRACT

We examine the relation between the intraday volume of different types of traders and the implied volatility skew. Using the Black (1976) model, we show that hedging strategies by certain types of traders affect the implied volatilities for T-bond futures options. However, in contrast to popular wisdom, we do not find evidence that speculative strategies affect implied volatilities. In addition, we find that the effect of excess demand on prices is disparate. In particular, the general public traders who are off-the-floor consistently buy high and sell low in pursuit of protection from risk, while floor traders buy low and sell high.

Since the stock market crash of 1987, the graph of stock option implied volatilities for differing strike prices has consistently appeared as a curve (smile or skew), contrary to the constant volatility prediction of the Black-Scholes model. Alternative models, such as Rubinstein's "Implied Binomial Tree" method (1994), adapt option pricing models to incorporate the volatility skew into option pricing. Our premise is that supply-demand imbalances for different strike prices, arising from the implementation of option strategies, also are a factor in determining volatility skews.

In order to examine the relation between volume and implied volatility skews, we employ intraday buy and sell volume by four types of traders: market makers, clearing members, floor traders trading for other exchange members, and the general public. These data allow us to examine a number of conjectures on the uses of calls and puts, the types of trades made across strike prices, and what option strategies can be attributed to different groups of traders. Thus, our approach investigates the effects of economic pressures rather than model inadequacies on the implied volatility patterns. Consequently, this research examines whether specific traders bid up (or down) the price of certain options relative to other options, thereby causing a pattern of differing implied volatilities. This approach examines Buraschi and Jackwerth's (1998) contention that "returns are driven by at least some additional factor compared to returns on at-the-money options," and that "away-from-the-money options are used by specialized clientele, such as portfolio insurers."

We find that, like equity options, T-bond futures options also exibit a volatility skew, in contradiction to the popular belief that only equity options have such skews. More importantly, we find that the volumes of out-of-the-money puts and, to a lesser extent, in-the-money calls, are most strongly associated with the T-bond futures option's skews. These results support the hypothesis that traders are engaging in hedging strategies to protect T-bond futures positions. Our findings are also consistent with the implied non-normal probability distributions derived from Rubinstein's (1994) implied binomial tree method. Finally, we show that the general public typically pays too much when they buy out-of-the-money puts and receives too little when they sell. The general public, as well as other groups, also take costly positions for other types of option positions associated with hedging. As a whole, these results show the importance of supply and demand in the pricing of T-bond futures options and how different groups of traders behave in disparate ways in their trading activities. They also imply that the general public, which has less timely information, trades at prices that are adversely distant from the fair option price.

I. The Evolution of the Implied Volatility Smile

If the Black and Scholes (1972) and Black (1976) option pricing models adequately describe market behavior then all options for a given asset should possess equal implied volatilities across all available strike prices (of the same expiration), since the volatility of the underlying asset is equivalent for each option. However, empirical evidence shows a *non-constant* implied volatility for options with differing strike prices and times to maturity (for example, see Dumas, Fleming, and Whaley (1998) and Jackwerth (2000)). This pattern is referred to as a "smile" when both the in- and out-of-the-money implied volatilities are larger than the near-the-money implied volatility, and a "smirk" or "skew" when either the in- or the out-of-the-money implied volatilities are significantly larger than the near-the-money implied volatility.

The investigation to date of implied volatility patterns across strike prices has centered on the inadequacies of the Black-Scholes/Black models and the benefits of alternative models. For example, Rubinstein (1994) developed the implied binomial tree method to incorporate non-constant implied volatilities. His model extracts the risk-neutral implied probability distribution from the actual implied volatilities. The resultant empirical non-lognormal probability distribution for *stock* options is skewed to the left, reflecting traders apparent concerns about a potential "crash."

Earlier option pricing research examined the "mispricing" of options in relation to the Black-Scholes (1973) model. MacBeth and Merville (1979, 1980) find that the Black-Scholes model systematically overprices deep-out-of-the-money calls and underprices deep-in-the-money calls. However, Black (1975) claims that the biases are in the opposite direction, while Rubinstein (1985) shows that the direction of the mispricing changes over time.

These mispricing biases encouraged researchers to focus on observing the pattern in implied volatilities, especially over differing strike prices. The resultant pattern of larger implied volatilities for in- and/or out-of-the-money strikes is labeled the implied volatility "smile" (or later the "skew"). Das and Sundaram (1998), Dupire (1993), Jackwerth (2000) and Rubinstein (1994) associate the implied volatility skew to the failure of the Black-Scholes assumption of constant volatility over time and to the lognormality of the asset returns. In other words, the Black-Scholes model assumes a constant global volatility, while differing implied volatilities across strikes/time are associated with local volatilities that change with market levels and times to expiration. Rubinstein (1994) developed an implied binomial tree method to fit these differing local volatilities for the constant volatility binomial tree, without losing the theoretical advantages of the Black-Scholes model. This method also allows for the determination of an implied risk-neutral probability distribution conditional on the asset price.[1] Rubinstein (1994) and Jackwerth and Rubinstein (1996a) find that the implied probability distribution since the 1987 crash is skewed to the left and has greater kurtosis than the lognormal, implying that traders or hedgers are concerned about a large decline in asset prices. Table II of Jackwerth and Rubinstein supports a concern about the risk of a price decline among traders given that (at-the-money) option implied volatilities are almost always biased upward in relation to historical volatility measures.[2]

Jackwerth and Rubinstein (1996b) test seven option valuation models to determine their ability to forecast future implied volatility smiles. These models are the classic Black-Scholes model (constant implied volatilities across strikes), two naive smile-based predictions using today's observed smile as the prediction, two versions of Cox's (1997) constant elasticity of variance (CEV) model, and two implied binomial tree models. The CEV models incorporate the assumption that the local volatility is negatively correlated with the underlying asset price, a factor found to be true historically. The CEV model also allows for jumps in prices.[3] Jackwerth and Rubinstein find that the naive relative and absolute smile models provide the best predictions of the future smile.[4] These models use constant

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[1] Jackwerth and Rubinstein (1996a) show how to best fit the jagged local volatility and probability distributions. Derman, Kani, and Zou (1996) discuss the local volatility surface in detail. Dupire (1993) and Derman, Kani, and Chriss (1996) use a trinomial lattice to fit (exactly) the option prices to the time variation of volatility. Trinomial trees have more parameters than binomial trees, providing flexibility in fitting the smile, while Rubinstein uses a deterministic volatility valuation model to fit the implied volatility curve. Corrado and Su (1996,1997) approach the problem from another direction, namely developing a four parameter Black-Scholes model that includes skewness and kurtosis to incorporate the volatility skew. When they fit such a model to recent data they find significant skewness and kurtosis.

[2] Rubinstein (1994) and Jackwerth and Rubinstein (1996b) discuss the economic reasoning associated with the negative relation between implied volatilities and asset price (a skew) as well as reasons to hedge against price declines. See Duan (1997) for a GARCH option pricing model that incorporates these factors.

[3] Volatility itself has a stochastic component and there can be a jump in prices. The Black-Scholes model ignores these factors. Transactions costs also can affect the results. The implied binomial tree model assumes that the variation of local volatility with the market level and time is the dominant contribution to the smile.

[4] The unrestricted CEV model has a reasonably small error, but the unrestricted version of the CEV model is questionable on economic grounds.

volatility assumptions and are models typically employed by traders. Their results support using the basic Black-Scholes or Black model to obtain implied volatilities for forecasting purposes.[5] Das and Sundaram (1998) examine whether jump and stochastic volatility models better fit the implied volatility smile. They find that each model is consistent with some of the smile anomalies but neither fully explain the smile patterns. However, the overall superiority of the stochastic volatility model is consistent with traders employing options for protection against losses in the underlying asset. Buraschi and Jackwerth (1998) come to a similar conclusion concerning stochastic volatility models.

II. Hedging and Speculative Strategies for the Implied Volatility Curve

The literature on volatility skews shows that the higher implied volatilities associated with out-of-the-money equity puts and in-the-money calls has occurred on a consistent basis only since the crash of 1987. Using the implied binomial tree method since 1987 results in implied probability distributions that have significant negative skewness. The associated economic reasoning is that options traders desire protection against large market declines. Since these traders are willing to pay more for loss protection, higher implied volatilities are greater for lower strike prices. If traders execute option strategies corresponding to this need for protection, then the volume of option trading by type of strategy will reflect this need.[6] The remainder of this section explains how trading strategies affect implied volatilities and develops a hypothesis about the relationship between hedging behavior and

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Dumas, Fleming, and Whaley (1998) use the S&P 500 index option to fit and examine the implied volatilities over time, with the objective of finding a stable implied volatility function. They find that the fitted volatility function deteriorates within one week.

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The only examination of option volume in relation to mispricing is by Long and Officer (1997). They show that mispricing errors are significantly larger on high-volume days, suggesting that changing supply and demand information affects option mispricing. However, they do not examine the relationship between option volume and implied volatility. In a theoretical work on trading volume, Blume, Easley, and O'Hara (1994) find that volume provides information not found in prices alone.

implied volatilities. In the following section we use option volume by type of trader to test this hypothesis.

Implied volatility curves have three basic shapes, or skews. The first shape describes higher implied volatilities for lower strike prices (out-of-the-money puts and in-the-money calls) and/or lower implied volatilities for higher strike prices (in-the-money puts and out-of-the-money calls). We label this negatively sloped curve as an "investment volatility skew." The economic explanation for this negatively sloped pattern is the trade-off between hedging needs and option cost. If an investment manager wants to protect against a price decline then (s)he could purchase protective puts and/or sell covered calls. Such managers purchase out-of-the-money puts (those with lower strike prices (K) than the asset price (F), i.e. K/F < 1.0) to obtain complete protection below the strike price, taking some downside risk with the out-of-the-money strike in order to reduce the cost of the option transaction. The higher demand for puts increases the premiums of the lower put strike prices (causing higher implied volatilities), thereby creating a downward sloping implied volatility curve for the lower strike prices, i.e. for K/F < 1.0. Moreover, the synthetic market between calls and puts at each strike price (put-call parity) causes in-the-money calls with lower strike prices (K/F < 1.0) to increase in price along with the corresponding out-of-the-money puts. These higher prices cause higher implied volatilities.

If portfolio managers sell covered calls then they obtain some protection by receiving the option price. Often, traders sell out-of-the-money calls (those with higher strike prices than the asset price, i.e. K/F > 1.0) to allow for a combination of some downside protection and some upside appreciation potential. The sale of these calls reduces the prices of the higher strike price calls (causing lower implied volatilities), thereby creating a downward sloping curve for strike prices with K/F > 1.0. As with the situation above, put-call parity also causes puts with higher strike prices (K/F > 1.0) to decrease in price with the corresponding in-the-money calls (which are associated with the lower implied volatilities).

The second type of volatility skew has lower implied volatilities for the lower strike prices and higher implied volatility for the higher strike prices. We label this positively sloped implied volatility curve as a "demand volatility skew." Such a curve exists when a trader wants to protect against an *increase* in prices and chooses to buy protective calls and/or sell covered puts. Again, such hedging is commonly executed with out-of-the-money options. Thus, puts with lower out-of-the-money strikes will decrease in price (causing lower implied volatilities) as they are sold for hedging purposes, while call options with higher out-of-the-money strikes will increase in price (causing higher implied volatilities) as hedgers buy these calls. Correspondingly, from put-call parity, the lower strike price calls will have lower implied volatilities while the higher strike price puts will show higher implied volatilities. Both investment and demand skews can exist for only one side of the at-the-money strikes ($K/F < 1.0$ or $K/F > 1.0$), in which case they are labeled "smirks."

The third type of volatility skew is a "balanced volatility skew" (or "smile") that has higher and nearly equal implied volatilities for equidistant away-from-the-money options and lower implied volatilities for near-the-money options. A balanced volatility skew occurs when one type of institution protects against lower prices, while another type of institution protects against higher prices.

Market participants claim that speculators also affect implied volatilities by paying more than the fair price for options, especially for call options. Traders associate this behavior for call options with optimistic forecasts of future prices in the underlying asset - especially individual stocks. Similarly, pessimistic forecasts will increase the demand (and price) for put options. Speculators typically buy near-the-money options, since they have the most leverage, although speculative trading could extend to away-from-the-money options.

We hypothesize that a pattern of implied volatilities can be linked to the behavior of particular types of traders. If traders are risk averse, they will pay higher prices for options that allow them to hedge perceived risk. This behavior will result in higher implied volatilities for away-from-the-money options, particularly out-of-the-money puts. If traders are risk seeking, then speculative needs will drive the implied volatilities higher for near-the-money options. A balance between hedgers and speculators should result in no apparent pattern. Moreover, particular groups of traders may differentially influence the skew due to their proximity to the trading floor, which gives them knowledge of current price dynamics and the bid-ask spread.

III. Methodology and Data

Previous research on stock index options suggests that traders will pay higher option prices than those calculated by a fair pricing model to protect against a decline in prices. These higher prices appear as higher implied volatilities in the strike price-volatility skew relation. Traders protecting against price declines can employ a variety of commonly used option hedging strategies that rely on using differing strikes, calls and puts, and long and short positions. Consequently, the breakdown of volume by type of trader and by position (buy/sell) could provide valuable insights into the relation between implied volatility and option strategies. In fact, Daigler and Wiley (1999) show that volume by type of trader is strongly associated with the volatility of futures contracts. Similarly, trader category volume also could affect the option premium. Our approach employs detailed transaction trading activity by type of trader to determine the impact of volume on the implied volatility skew. This complements previous research on implied volatility patterns that alters the option pricing model to explain the skew.

The analysis of the relation between intraday volume and the implied volatility curve proceeds in two steps. First, we calculate implied volatilities from options and futures transactions data. Second, we relate the buy and sell volume data by type of trader to the excess implied volatility over the at-the-money implied volatility at each strike price to test whether volume is associated with the implied volatility skew.

A. Data and Calculating Implied Volatilities

We analyze every price and associated volume for T-bond options on futures contracts for one year, comprising over 200 trading days of price and volume data. These contracts have substantial option volume for a number of the strike prices. Implied volatilities are calculated for each options trade. We use the futures transaction immediately before the options trade to determine the underlying futures price for the option pricing model (typically there is less than 10 seconds difference between the futures and options trades). We then employ the Black model (1976) for pricing options on futures to calculate the implied volatility for each transaction.

The reasoning for employing the Black constant implied volatility model is threefold. First, we desire the implied volatility pattern from the basic Black option pricing model in order to determine if volume by type of trader can explain the resultant implied volatility pattern. Second, as noted above, Jackwerth and Rubinstein (1996b) find that the naive skew patterns used by traders and employing the constant volatility option pricing models do the best job of forecasting the skews. Third, other research on futures options supports using the Black model, e.g. Barone-Adesi and Whaley (1987), Ederington and Lee (1996), Hamid (1998), Ramaswamy and Sundaresen (1985), and Shastri and Tandon (1986).[7] Hence, the Black model provides useful estimates of implied volatility for our purpose of relating option volume to the volatility skew.

Trading volume falls as an option contract approaches expiration; therefore our analysis switches to the deferred contract one week before option expiration. T-bond futures options expire two weeks before the futures delivery period, which starts on the first day of the expiration month. For T-bond futures options the March, June, September, and December options have the greatest trading volume and trade actively for at least three months prior to expiration. We do not use the off-cycle expiration months here due to low trading volume and the difficulty of constructing a continuous series

7 Barone-Adesi and Whaley (1987) show that a significant difference between the American and European models only occurs for in-the-money options. The key patterns with volume examined in this paper involve out-of-the-money options. Hamid (1998), Ramaswamy and Sundaresen (1985), and Shastri and Tandon (1986) all find that the European option model provides a good or indistinguishable approximation to the American option price.

of values.[8]

B. Volume by Type of Trader

We investigate the relation between intraday trading activity and implied volatility by employing buy and sell volume for four categories of traders for T-bond options on futures contracts. Each observation provides volume for each of the four trader categories for each option price and each option strike during the day. The data set contains the buy volume and sell volume for each of the following four types of traders:

CTI1: volume for the local floor trader's own account or for an account which (s)he controls. Floor traders, especially scalpers, trade for the short-term and provide liquidity to the market by taking the opposite positions of longer-term traders.

CTI2: volume for the clearing member's house account. Clearing members trade for hedging purposes and to benefit from mispricing of the futures contracts ("value traders").

CTI3: volume for an exchange member executing trades for another member, or an account controlled by other such members, labeled "other floor traders." An example of a CTI3 trade is a trader from the futures pit who trades an option in order to hedge a position.

CTI4: volume for the general public, including individual traders. This last category is most likely dominated by traders with limited market information.

These categories are used industry wide. Moreover, trades are assigned to groups based on the strict definitions identified above; self designation of trades is not permitted.

C. Implied Volatilities as a Function of Volume

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[8] Option expirations for non-financial cycle months (e.g. February) exist for approximately one month. This restriction, combined with the need to avoid options within one week of expiration makes these options undesirable for this study.

We employ the following regression model to test whether a relation exists between implied volatility and CTI volume for the various strike prices for T-bond futures options:

$$IV(K_i,t) - IV(K_{at},t) = a + b_1 \log(K/F) + b_2 T + \Sigma b_j \, CTI(j) \qquad (1)$$

where $IV(K_i,t)$ and $IV(K_{at},t)$ are the implied volatilities for strike price K_i and the at-the-money strike price $K_{at,}$ respectively, at time t. K/F is the strike price divided by the futures price, T is the time until option expiration in days, and CTI(j) is the buy/sell volume for each CTI category. The at-the-money implied volatility is determined as a weighted average from the two closest strike prices. Separate regressions are fit for in- and out-of-the-money puts and calls, since different potential strategies exist and substantially different volume occurs for each of these four categories.

Table 1 provides summary information on implied volatilities, the strike to futures price range, and CTI volume by the four categories of call and put options. The number of intraday observations varies substantially by the type of option, with out-of-the-money puts providing the most observations and the largest volume per observation. Out-of-the-money calls are second largest. In-the-money calls have the greatest range of implied volatility differences (from the at-the-money implied volatility), as well as the largest implied volatility for an option.

TABLE 1

IV. Results

A. The Implied Volatility Skew

To examine the relationship between CTI volume and the volatility skew we associate CTI volume to T-bond futures options implied volatility differences (from the associated at-the-money implied volatilities). Figure 1 shows a typical smoothed implied volatility skew curve over a 5% strike price range around the current at-the-money implied volatility for the sample period. This figure is best described as an investment skew for K/F < 1.0, with an essentially flat relation for K/F > 1.0.

Figure 2 plots each observation of the implied volatility for a single trading day selected at random from the sample period. Predictably, a dispersion of implied volatilities exists for similar K/F values, although puts have a smaller dispersion of implied volatilities than do calls (especially for at-the-money and in-the-money calls). Figure 2 clearly shows that the volatility skew for K/F < 1.0 is dominated by the out-of-the-money puts. Statistical tests verify this impression.

FIGURES 1 AND 2

B. Implied Volatility Relationships by Type of Option

We separate the 22,000 observations on option price and volume for the T-bond futures options data into the four groups of in- and out-of-the-money options for both calls and puts. We associate each group with differing option strategies, since each strategy creates different supply or demand characteristics. If the demand to buy (or supply to sell) one type of option increases due to an abundance of traders executing a particular option strategy, then the price of that option can differ from the fair option price, causing the associated implied volatility to differ from the at-the-money implied volatility. All tests assume that the at-the-money option price and implied volatility is fair, which is consistent with previous studies on the pricing of options (as first assumed by MacBeth and Merville (1979)).

In equation 1 we regress implied volatility differences (from the associated at-the-money implied volatilities) on the log(K/F), the time to maturity of the option, and the CTI buy and sell volume variables for the four types of options. Table 2 shows regression R^2s and significant probability and t-values for equation 1. Only results for out-of-the-money puts and in-the-money calls are significant. Table 3 shows the associated regression coefficients, where significant. These two models show a good fit between implied volatility and the independent variables, with R^2 values of 58.5% and 30.4%, respectively. The put results are consistent with the strategy of buying out-of-the-money puts for downside protection (the investment volatility skew for K/F<1 described previously).[9] Specifically, the positive and significant buy volume coefficients show that as the volume of puts purchased increases, the positive difference from the at-the-money implied volatility increases. All CTI categories provide a highly significant and positive coefficient for put purchases.[10] These results confirm the explanation of others (e.g. Rubinstein (1997)) for the shape of the implied volatility skew, namely that hedgers purchase puts for protection against potential "crashes."

TABLES 2 AND 3

In addition, there is evidence of a demand skew for K/F < 1.0 as the CTI2 and CTI4 groups sell out-of-the-money puts. Their selling action, consistent with creating covered put combinations, results in lower implied volatilities in relation to at-the-money options.[11,12] However, since the K/F < 1.0 skew is downward sloping as K/F increases, this suggests that these groups sell more near-the-money puts and avoid farther out-of-the-money puts.

The in-the-money call results for K/F < 1.0 are significant only for purchases by the CTI2 and CTI4 groups. These positive coefficients are consistent with a put-call parity argument of selling the higher implied volatilities for out-of-the-money puts as well as hedging by buying in-the-money calls. However, such an argument is economically rational only for the CTI2 commercial traders, who possess the technology and ability to trade at low cost to fully benefit from the mispricing of options and

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9 Speculators tend to buy near-the-money options to maximize leverage.

10 CTI1 (marketmaker) volumes are not used as a variable since marketmakers sell when the other groups buy and vice-versa, causing an extremely high intercorrelation and a near-singular matrix. Separate regression results (not shown here) confirm the almost equivalent results (but opposite coefficient values) for CTI1 volume data.

11 Covered put positions are not unusual for the T-bond futures market, where short positions in the futures are as common as long positions.

12 The CTI3 group are marketmakers who are off-of-the-floor. Hence, they often act similar to other market makers and thus have coefficients with signs that are opposite the CTI2 and CTI4 traders.

to hedge other positions. The higher implied volatilities for in-the-money calls for the CTI4 general public (who presumably cannot observe mispricing or effectively act on it, since they are off-the-floor) could be due to speculative call purchase strategies. However, such actions would mean that these speculators prefer to buy more costly in-the-money calls than less costly (both in price and implied volatilities) near-the-money calls. Finally, the regression results do not provide evidence that traders sell calls for hedging purposes, since this would create positive significant coefficients for the CTI sell variables for the in- or out-of-the-money call equations. We will deal with the actions of the general public (CTI4s) in more detail later.

In conclusion, there is evidence both of an investment smirk and a demand skew for options where $K/F < 1.0$. A key element in distinguishing between these two skews is the predominant purchase of out-of-the-money puts for downside protection in an investment skew. These put purchases drive the overall shape of the implied volatility skew.

C. Net Cumulative Volume as the Implied Volatility Difference and K/F Changes

Another approach to showing the importance of the trading activity of the various CTI groups is to examine the cumulative net volume positions for each group of trader, using the size of the implied volatility differences as the criteria to accumulate the positions. These figures will show if any group(s) consistently buy or sell *net* option positions with high implied volatilities. Figure 3A to 3D provide these results, with the largest implied volatility differences at the left. Figure 3A clearly illustrates that the general public takes large positive net positions in high implied volatility out-of-the-money puts, while market makers (the CTI1s) sell these puts (take large net negative positions in high implied volatility puts). As one moves to the right on Figure 3A, the net positive position of the general public declines (they sell more of the lower implied volatility positions then they purchase), while the commercials (CTI2s) take a relatively large net positive position in lower implied volatility out-of-the-money puts. These results provide evidence to supplement the regression results, namely that the general public is the main buyer of high implied volatility out-of-the-money puts. More strongly put, the general public is likely to pay more for put option positions than the CTI1, CTI2, and CTI3 traders who have more direct access to the floor of the exchange.

FIGURES 3A TO 3D

Figure 3B illustrates that the general public also buys high implied volatility far-in-the-money call options while it sells lower implied volatility calls. Market makers take the opposite net position, while the commercial traders consistently sell the in-the-money calls, which is most likely associated with covered call strategies. While the regression models are not significant when applied to in-the-money puts and out-of-the-money calls, Figures 3C and 3D show that the cumulative net volume positions taken with these options do differ by trading groups. The general public sells in-the-money puts, although mostly those with lower implied volatilities, while the market makers take a net positive position in these options. We interpret this as additional evidence that market participants sell puts to create covered put positions, as we find with the regression results for the out-of-the-money puts. Finally, Figure 3D for out-of-the-money calls shows a sharp increase in the net general public call position for the largest implied volatilities, which then reverses itself. Such behavior suggests that the general public likes to speculate in purchasing way-out-of-the-money calls (although buying protective calls to protect a short position - at an expensive price - is also consistent with these results).

When K/F is substituted for the implied volatility difference (not shown here for space considerations) the net cumulative volume graphs are very similar to Figures 3A to 3D. This similarity is due to the close association between the implied volatility difference from the at-the-money volatility and the extent the option is away-from-the-money. As K/F changes, the general public takes a large net positive position in way-out-of-the-money puts and keeps this large position as K/F increases towards 1.0. Commercials also take a positive net position, but only for puts that are nearer-the-money. Market makers and off-the-floor traders (CTI3s) take the opposite positions. Similarly, the general public takes a large positive position for way-in-the-money calls, but the commercials take a negative net position in these calls. The results for the in-the-money puts and out-of-the-money calls are also consistent with previous results. In particular, the general public takes a large net position in way-out-of-the-money calls, while the commercials take a medium size position in nearer-to-the-money calls. These results support the idea that trading strategies vary significantly by trader type.

D. Implied Volatility Differences Ranked by Volume and Strike Price

In order to determine if the number of contracts traded at a given option price affects the results, we segregate the data into those observations with more than 100 contracts traded at a given price and those with fewer than 100 contracts. Tables 4 and 5 illustrate these results. First, these tables show that the higher volume trades have greater explanatory power (higher adjusted R^2 values) than the lower volume trades. Second, the high volume results are more like the results in Tables 2 and 3 than the low volume regressions. And third, the high volume results have higher significant coefficients for the important out-of-the-money puts regression compared to the low volume results. Hence, in addition to supporting the earlier results, Tables 4 and 5 show that volume does matter, and that higher volume trades have a greater effect on the implied volatility skew. Moreover, Tables 2 and 4 show that, overall, the general public's volume is more important than the other groups in determining the implied volatility skew. As with the entire data set, the in-the-money puts and out-of-the-money calls had minimal explanatory power either for the skew or associating volume to implied volatility differences.

TABLES 4 AND 5

E. Implied Volatility Differences Ranked by Option Price

As shown previously, certain groups take large net positions with high implied volatility as well as with away-from-the-money options. These results suggest that option price may play a role in the volatility skew, since way-out-of-the-money options are lower in price and therefore a small change in option price could substantially increase their implied volatilities. Tables 6 and 7 investigate the importance of option price for the implied volatility/group volume relationship by separating price into four groups. The results are ranked by increasing or decreasing price according to explanatory power. The R^2s are monotonic with option price, with large differences in the R^2 values for different option price ranges.

TABLES 6 AND 7

The out-of-the-money put results show dramatic reductions in the fit of the regressions as the price of the puts increase (as one goes from more out-of-the-money to nearer-the-money). This is consistent with traders buying puts for protection and preferring farther-out-of-the-money puts for this purpose, since they cost less. When we segregate the data in this way the dominance of the general public volume in the regressions becomes even more apparent in terms of which variables are significant. Since the signs of the coefficients match earlier results, the interpretation of the strategies employed by these traders remains as previously discussed.

The in-the-money call results show a similar pattern to the puts, both in terms of the decline in the R^2 values and the significance of the coefficients, although none of the volume variables are significant for the regressions when the option price is below 2.00. The in-the-money put and out-of-the-money call results are significant for 3 of 4 equations each, much stronger than the previous results for these categories, although the importance of the individual volume coefficients is inconsistent.

Overall, segregating the data by option price provides information concerning the fit of the regression models and the pattern of significant coefficients not available from previous results. In addition, such segregation illustrates that even the in-the-money put and out-of-the-money call data possess some significant relationships with implied volatility differences.

F. Position Deltas and the Mispricing of Options by Traders

The illuminating results when we rank the data by option price, as shown in the previous section, suggests that an analysis of the risk of option portfolios held by different types of traders would provide additional insights to option pricing. Consequently, we calculate the delta for each actual option price by using the implied volatility of the option as the measure of the future contract volatility. We then determine the cumulative position delta by adding the delta times the net volume for the associated option to the net position delta for previous options, as ranked by the ratio of strike to futures price. We determine this net position delta for two sets of observations: those observations that have implied volatilities larger than the basic skew (as determined by using only the log(K/F) and the time to maturity) and those observations with implied volatilities that are smaller than the basic skew.

Figures 4A and 4B show the net position deltas for the observations above and below the skew line for out-of-the-money puts. A striking feature of these two figures is that the position deltas for the general public are negative as K/F increases for observations above the skew line, but positive as K/F increases for observations below the skew line. A negative position delta results from purchasing puts, since puts have negative deltas. Similarly, a positive position delta results from selling puts. Hence, these figures show that the general public *purchases* puts that have higher than average implied volatilities (prices) for their strikes (as observations are above the skew line in Figure 4A), while they sell puts that have lower than average implied volatilities (prices) for their strikes (as observations are below the skew line in Figure 4B). This is the most significant evidence that the general public buys at too high a price and sells at too low a price when they execute their option strategies.

FIGURES 4A AND 4B

Figure 4A also shows that the commercial traders pay too high a price on average when they purchase put options but, unlike the general public, Figure 4B shows they sell puts at higher prices than the average implied by the skew. Both the general public and commercials have only small position deltas for way-out-of-the-money options (low K/F values), since the price and delta of these options are extremely low. Hence, these traders are willing to pay only a small option price for protection when the option provides protection only for large losses.

Figure 5A shows that the general public also pays too much when buying in-the-money calls that are above the skew line. However, they also pay too little when they purchase these calls that are below the skew line (Figure 5B). Similarly, the other position delta figures show that certain groups of traders consistently buy (sell) options that are above (below) the skew line, thereby paying too much or receiving too little for the options. But these same groups also consistently buy (sell) options that are below (above) the skew line. Only the general public's out-of-the-money puts have opposite position delta values for observations above and below the skew line,

FIGURES 5A TO 7B

These results provide conclusive evidence that certain option traders executing specific strategies are willing to pay a higher price than the fair value given by the Black model and/or receive a lower price than the fair value when they sell an option. In particular, the general public trades at "inefficient" prices when dealing with out-of-the-money put options. These results are consistent with Jackwerth (2000), who finds mispricing in general for options associated with the implied volatility skew.

V. Conclusions and Usefulness of the Results

We show that T-bond futures options exhibit an investment skew or smirk when K/F < 1.0, similar to the skew shape typical for stock options. More importantly, our results show that volume by type of trader and hedger strategy help explain the implied volatility skew. Finally, net position data firmly establish that certain types of traders consistently buy options at too high a price and sell options at too low a price, especially to execute hedging strategies.

The use of buy and sell volume shows that the investment skew associated with buying out-of-the-money puts for hedging clearly drives the implied volatility curve for T-bond futures options. Moreover, the general public is the key group associated with this hedging strategy, with commercial trades being important in some circumstances. Both the regressions of implied volatility differences on volume and the cumulative net volume graphs support these results. Interestingly, while there is substantial evidence that hedging strategies affect the implied volatility skew, there is very little evidence that speculative trading affects implied volatilities.

We extend and enhance our results by ranking the observations by volume size and by option price. Trades with larger volume create a better regression fit as well as providing support for the relationships concerning hedging strategies. Ranking by option price shows the importance of price in the implied volatility relationship. In fact, the ranking of option price emphasizes the importance of the general public as well as finding significant relationships for in-the-money puts and out-of-the-money calls that are insignificant when we use all of the data.

A key conclusion of the net cumulative volume graphs for position deltas is that certain groups of traders, usually the general public, consistently take positions at disadvantageous prices. We show the mispricing by calculating the cumulative position deltas for option trades both above and below the implied volatility skew line. The general public consistently buys out-of-the-money puts at too high a price and sells puts at too low a price. Other mispricing occurs for different types of options positions and types of traders, but the out-of-the-money puts positions are the most compelling, especially since they are directly linked with the implied volatility skew. These results are the first conclusive evidence that a specific group of traders consistently take positions at disadvantageous prices (implied volatilities).

Our results are important for several reasons. First, they show the significance of trading strategies for option pricing and implied volatilities. Thus, certain types of traders employ specific trading strategies, and these strategies differ from group to group. Second, the association of volume with implied volatility suggests that the Black model does not include all of the factors necessary to price options, in particular the effect of concentrated volume on one side of the market. Third, based on the Black model, option mispricing often occurs due to specific types of supply/demand associated with option strategies. Most important, traders off-of-the-floor appear to consistently buy high and sell low in pursuit of protection from risk. In conclusion, the study of option volume by type of trader and by option strategy is a fruitful area for further investigation as we refine our knowledge of option pricing and the dynamics of the implied volatility curve.

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Table I

Summary Statistics for Implied Volatility (IV) and CTI Volume for T-bond Futures Options Skews

We separate all option trades during the sample period into calls and puts, in- and out-of-the-money. Implied volatility differences are the implied volatility for the option price minus the implied volatility for the associated at-the-money option. Volume per observation is measured by the volume at each option price. We accumulate option trades such that each observation is for a unique option price, strike price, and day. K stands for strike price, F is the futures price.

Type of Option	No. Obs.	Range of K/F	Range of IV Differences	Av. of the IV Differences	Range of IV	Range of At-the-Money IV	Max Total Volume per Obs	Avg Total Volume per Obs
Puts: out-of-the-money	8,063	0.8811 to 1.0	0.0509 to -0.0290	0.004873	0.0706 to 0.1621	0.0782 to 0.1180	25,808	613.7
Calls: in-the-money	4,706	0.9233 to 1.0	0.1639 to -0.0598	0.004914	0.0495 to 0.2669	0.0782 to 0.1180	5,716	206.1
Puts: in-the-money	2,076	1.0368 to 1.0	0.1083 to -0.0695	-0.00084	0.0314 to 0.2054	0.0782 to 0.1180	4,248	126.3
Calls: out-of-the-money	7,200	1.0909 to 1.0	0.0284 to -0.0202	-0.00099	0.0682 to 0.1438	0.0782 to 0.1180	10,782	524.6

Table II

Adjusted R^2 and Volume Significance Values for Regressions of Differences in Implied Volatility on CTI Volume and Skew Variables

We regress the difference in implied volatility between each option price and the associated at-the-money implied volatility on the log(K/F), time to maturity of the option, and the volume of the purchases and sales of each of the CTI groups. CTI2s are commercial traders trading for their own account, CTI3s are floor traders who are making trades from outside the pits, and CTI4 are the general public. We accumulate option trades such that each observation is for a unique option price, strike price, and day. Using CTI1 (market makers) makes the matrix near singular and hence is omitted. Results for CTI1 are almost equivalent (but opposite) the results in this table. Significant variables are in bold.

			Significance Probability Levels and Associated t-values (in parens)					
Type of Option	No. of Observations	Adjusted R^2	CTI2 Buys	CTI3 Buys	CTI4 Buys	CTI2 Sales	CTI3 Sales	CTI4 Sales
Puts: out-of-the-money	8063	0.585	**0.033 (2.136)**	**0.001 (3.263)**	**0.000 (5.383)**	**0.004 (-2.890)**	**0.021 (2.209)**	**0.000 (-4.992)**
Calls: in-the-money	4206	0.304	**0.001 (3.445)**	0.453 (-0.750)	**0.025 (2.243)**	0.659 (0.441)	0.271 (1.101)	0.424 (-0.799)
Puts: in-the-money	2076	0.006	Equation is not significant					
Calls: out-of-the-money	7200	0.012	Equation is not significant					

Table III

Coefficients for the Regressions of Differences in Implied Volatility on CTI Volume and Skew Variables

We regress the difference in implied volatility between each option price and the associated at-the-money implied volatility on the log(K/F), time to maturity of the option, and the volume of the purchases and sales of each of the CTI groups. CTI2s are commercial traders trading for their own account, CTI3s are floor traders who are making trades from outside the pits, and CTI4 are the general public. We accumulate option trades such that each observation is for a unique option price, strike price, and day. Only significant variables are listed. Using CTI1 (market makers) makes the matrix near singular and hence is omitted. Results for CTI1 are almost equivalent (but opposite) the results in this table.

Type of Option	log(K/F)	Time to Maturity[a]	CTI2 Buys[a]	CTI3 Buys[a]	CTI4 Buys[a]	CTI2 Sales[a]	CTI3 Sales[a]	CTI4 Sales[a]
Puts: out-of-money	-0.5310***	-72.01***	0.905**	3.078***	1.605***	-1.270***	1.990**	-1.564***
Calls: in-the-money	-1.6420***	-106.67***	20.312***		6.864**			
Puts: in-the-money				Equation is not significant				
Calls: out-of-the-money				Equation is not significant				

[a] Coefficient times 1,000,000
* Significant at the 10% level
** Significant at the 5% level
*** Significant at the 1% level

Table IV

Adjusted R^2 and Volume Significance Values for Regressions of Differences in Implied Volatility on CTI Volume and Skew Variables: Observations Ranked by Volume

We separate each set of data for calls/puts and in-/out-of-the-money into two categories based on the volume per observation, where 100 contracts is the cutoff. We regress the difference in implied volatility between each option price and the associated at-the-money implied volatility on the log(K/F), time to maturity of the option, and the volume of the purchases and sales of each of the CTI groups. CTI2s are commercial traders trading for their own account, CTI3s are floor traders who are making trades from outside the pits, and CTI4 are the general public. We accumulate option trades such that each observation is for a unique option price, strike price, and day. Using CTI1 (market makers) makes the matrix near singular and hence is omitted. Results for CTI1 are almost equivalent (but opposite) the results in this table. Significant variables are in bold.

			Significance Probability Levels and Associated t-values (in parens)					
Type of Option and Volume Range	No. Obs	Adjusted R^2	CTI2 Buys	CTI3 Buys	CTI4 Buys	CTI2 Sales	CTI3 Sales	CTI4 Sales
Puts: out-of-the-money Volume ≥ 100	5066	0.616	**0.031** **(2.161)**	**0.002** **(3.035)**	**0.000** **(5.305)**	**0.005** **(-2.806)**	**0.034** **(2.117)**	**0.000** **(-4.809)**
Puts: out-of-the-money Volume < 100	2996	0.539	0.914 (-0.108)	0.686 (-0.404)	**0.004** **(2.902)**	**0.067** **(-1.831)**	0.644 (-0.462)	**0.000** **(-4.305)**
Calls: in-the-money Volume ≥ 100	1498	0.342	**0.001** **(3.463)**	0.721 (-0.357)	**0.035** **(2.105)**	0.669 (0.427)	0.242 (1.170)	0.747 (-0.323)
Calls: in-the-money Volume < 100	2708	0.284	0.368 (-0.900)	**0.051** **(1.949)**	**0.014** **(2.449)**	0.229 (-1.203)	0.869 (0.165)	**0.005** **(-2.784)**
Puts: in-the-money Volume ≥ 100	606	0.010	Equation is not significant					
Puts: in-the-money Volume < 100	1470	0.007	Equation is not significant					
Calls: out-of-the-money Volume ≥ 100	4520	0.013	Equation is not significant					
Calls: out-of-the-money Volume < 100	2680	0.017	Equation is not significant					

Table V
Coefficients for the Regressions of Differences in Implied Volatility on CTI Volume and Skew Variables: Observations Ranked by Volume

We separate each set of data for calls/puts and in-/out-of-the-money is separated into two categories based on the volume per observation, where 100 contracts is the cutoff. We regress the difference in implied volatility between each option price and the associated at-the-money implied volatility on the log(K/F), time to maturity of the option, and the volume of the purchases and sales of each of the CTI groups. CTI2s are commercial traders trading for their own account, CTI3s are floor traders who are making trades from outside the pits, and CTI4 are the general public. We accumulate option trades such that each observation is for a unique option price, strike price, and day. Only significant variables are listed. Using CTI1 (market makers) makes the matrix near singular and hence is omitted. Results for CTI1 are almost equivalent (but opposite) the results in this table.

Type of Option and Volume Range	log(K/F)	Time to Maturity[a]	CTI2 Buys[a]	CTI3 Buys[a]	CTI4 Buys[a]	CTI2 Sales[a]	CTI3 Sales[a]	CTI4 Sales[a]
Puts: out-of-the-money Volume ≥ 100	-0.5610***	-82.51***	0.860**	2.701***	1.488***	-1.159***	1.718**	-1.421***
Puts: out-of-the-money Volume < 100	-0.4972***	-61.87***			34.125***	-48.901*		-51.453***
Calls: in-the-money Volume ≥ 100	-1.9011***	-117.34***	21.375***		6.791**			
Calls: in-the-money Volume < 100	-1.4893***	-105.16***		221.16*	122.16**			-138.69*
Puts: in-the-money	Neither volume equation is significant							
Calls: out- of-the-money	Neither volume equation is significant							

[a] coefficient times 1,000,000
* Significant at the 10% level
** Significant at the 5% level
*** Significant at the 1% level

Table VI
Adjusted R^2 and Volume Significance Values for Regressions of Differences in Implied Volatility on CTI Volume and Skew Variables: Observations Ranked by Price

We separate each set of data for calls/puts and in-/out-of-the-money into four categories based on the price level of the option. We regress the difference in implied volatility between each option price and the associated at-the-money implied volatility on the log(K/F), time to maturity of the option, and the volume of the purchases and sales of each of the CTI groups. CTI2s are commercial traders trading for their own account, CTI3s are floor traders who are making trades from outside the pits, and CTI4 are the general public. We accumulate option trades such that each observation is for a unique option price, strike price, and day. Using CTI1 (market makers) makes the matrix near singular and hence is omitted. Results for CTI1 are almost equivalent (but opposite) the results in this table. Significant variables are in bold.

			Significance Probability Levels and Associated t-values (in parens)					
Type of Option and Price Range	No. Obs	Adjusted R^2	CTI2 Buys	CTI3 Buys	CTI4 Buys	CTI2 Sales	CTI3 Sales	CTI4 Sales
Puts: out-of-the-money P ≤ 0.25	1850	0.532	0.213 (1.246)	0.195 (1.295)	**0.015** **(2.432)**	0.157 (-1.415)	0.672 (0.424)	**0.064** **(-1.854)**
0.5 ≥ P > 0.25	1840	0.221	0.213 (1.245)	0.739 (-0.333)	**0.032** **(2.149)**	0.133 (1.502)	0.667 (-0.430)	0.103 -1.629
1.0 ≥ P > 0.5	2656	0.217	**0.074** **(1.788)**	0.670 (0.426)	**0.043** **(2.020)**	0.155 (-1.422)	0.236 (1.186)	**0.072** **(-1.799)**
P > 1.0	1717	0.054	0.521 (-0.642)	0.862 (-0.174)	0.710 (-0.371)	0.406 (0.832)	0.743 (0.328)	0.861 (0.137)
Calls: in-the-money P ≥ 2.75	962	0.375	**0.000** **(4.345)**	0.911 (0.112)	**0.031** **(2.156)**	0.167 (-1.382)	0.605 (-0.518)	0.219 (-1.231)
2.75 > P ≥ 2	982	0.180	0.109 (1.603)	0.463 (0.734)	**0.029** **(2.180)**	0.161 (-1.403)	0.890 (-0.139)	**0.068** **(-1.842)**
2 > P ≥ 1.25	1518	0.051	0.994 (0.007)	0.652 (-0.451)	0.282 (1.075)	0.191 (1.301)	0.946 (0.068)	0.114 (-1.583)
1.25 > P ≥.5	744	0.001			Equation is not significant			
Puts: in-the-money 1.25 ≥ P > .5	647	0.124	0.824 (0.222)	0.473 (0.718)	0.143 (1.467)	0.659 (-0.441)	0.348 (0.940)	**0.006** **(-2.743)**
2 ≥ P > 1.25	821	0.053	0.897 (0.129)	0.477 (-0.712)	0.119 (1.560)	0.443 (-0.768)	0.621 (-0.494)	0.898 (-0.128)
2.75 ≥ P > 2	466	0.049	0.467 (-0.728)	0.256 (1.136)	**0.026** **(-2.227)**	0.482 (0.704)	0.609 (-0.512)	**0.013** **(2.493)**
P > 2.75	142	0.021			Equation is not significant			
Calls: out-of-the-money P ≤ 0.25	1215	0.257	0.834 (0.209)	**0.083** **(-1.735)**	0.794 (0.262)	0.214 (-1.244)	0.867 (-0.167)	0.436 (0.779)
0.5 ≥ P > 0.25	1640	0.207	**0.002** **(3.147)**	**0.044** **(-2.018)**	0.309 (1.018)	0.255 (-1.138)	**0.081** **(-1.745)**	0.122 (-1.548)
1.0 ≥ P > 0.5	2612	0.070	0.778 (0.283)	0.418 (-0.810)	0.782 (0.276)	**0.064** **(1.851)**	0.921 (-0.099)	0.411 (-0.822)
P > 1.0	1733	0.023			Equation is not significant			

Table VII

Coefficients for the Regressions of Differences in Implied Volatility on CTI Volume and Skew Variables: Observations Ranked by Price

We separate each set of data for calls/puts and in-/out-of-the-money into four categories based on the price level of the option. We regress the difference in implied volatility between each option price and the associated at-the-money implied volatility on the log(K/F), time to maturity of the option, and the volume of the purchases and sales of each of the CTI groups. CTI2s are commercial traders trading for their own account, CTI3s are floor traders who are making trades from outside the pits, and CTI4 are the general public. We accumulate option trades such that each observation is for a unique option price, strike price, and day. Only significant variables are listed. Using CTI1 (market makers) makes the matrix near singular and hence is omitted. Results for CTI1 are almost equivalent (but opposite) the results in this table.

Type of Option and Price Range	log(K/F)	Time to Maturity[a]	CTI2 Buys[a]	CTI3 Buys[a]	CTI4 Buys[a]	CTI2 Sales[a]	CTI3 Sales[a]	CTI4 Sales[a]
Puts: out-of-the-money $P \le 0.25$	-0.9577***	-286.95***			1.255**			-1.059*
$0.5 \ge P > 0.25$	-0.4914***	-81.45***			1.194**			
$1.0 \ge P > 0.5$	-0.3818***	-32.99***	1.090*		1.000**			-0.869*
$P > 1.0$	-0.2372***	-7.580**						
Calls: in-the-money $P \ge 2.75$	-2.355***	-329.22***	125.46***		33.808**			
$2.75 > P \ge 2$		-108.71***			9.337**			-7.373*
$2 > P \ge 1.25$	-0.2966**	-45.616***						
$1.25 > P \ge .5$				Equation is not significant				
Puts: in-the-money $1.25 \ge P > .5$	-2.3615***	-117.11***						-12.632***
$2 \ge P > 1.25$	-0.9884***	-80.20***						
$2.75 \ge P > 2$	-1.1232***	-179.97***			-43.727**			51.709**
$P > 2.75$				Equation is not significant				
Calls: out-of-the-money $P \le 0.25$	0.6819***	-215.55***		-4.252*				
$0.5 \ge P > 0.25$	0.586***	-151.66***	2.652***	-3.919**			-3.099*	
$1.0 \ge P > 0.5$	0.2597***	-57.963***				1.191*		
$P > 1.0$				Equation is not significant				

[a] coefficient times 1,000,000
* Significant at the 10% level
** Significant at the 5% level
*** Significant at the 1% level

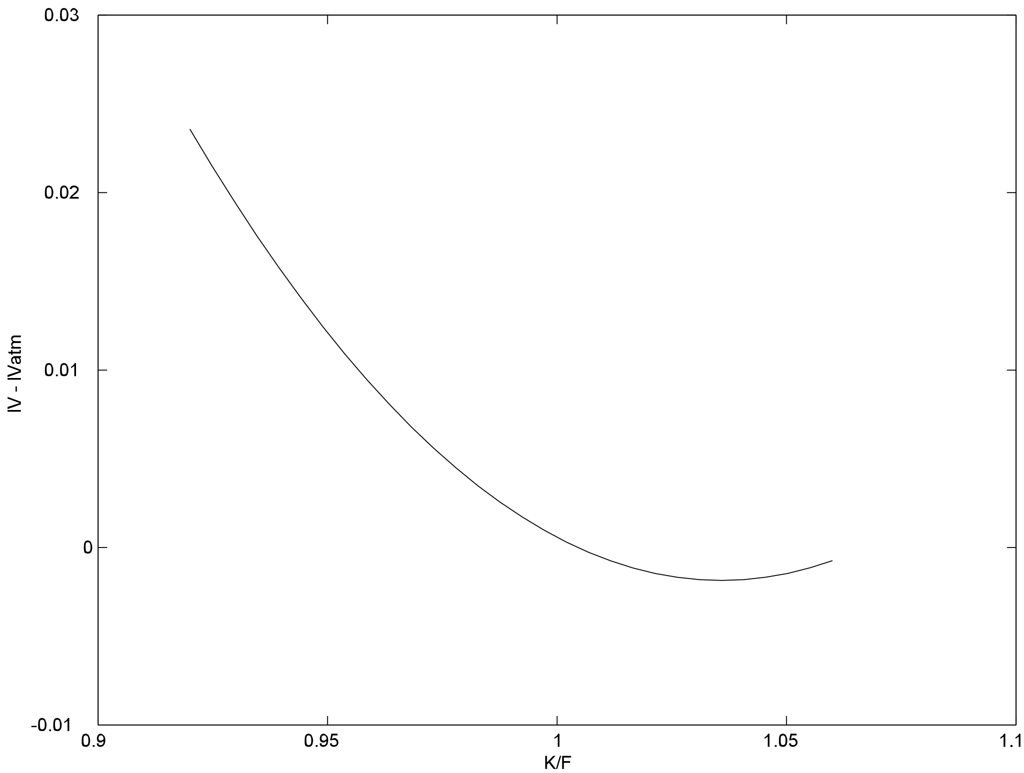

Figure 1. Implied Volatility Smile
A sample fit of deviations in implied volatility from at-the-money volatility (IV(Kat,t)) on the ratio of strike price to futures price (K/F) for T-bond futures and futures options.

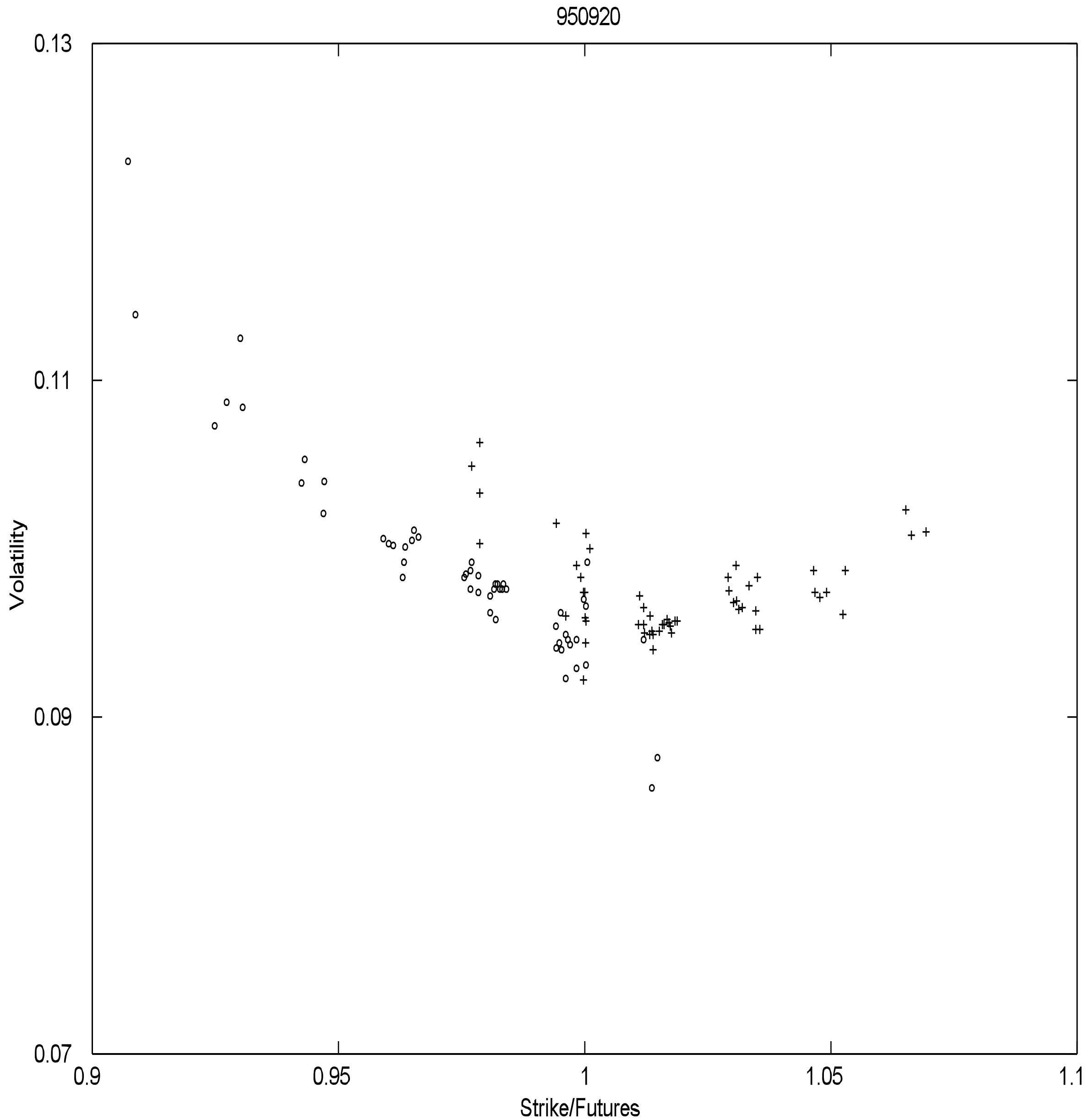

Figure 2. One Day Sample Implied Volatility for T-bond Futures Options
Implied volatilities are calculated for each option transaction recorded. The “o” points are puts and the “+” points are calls.