# Volatility Surface and Skewness in Live Cattle Futures Price Distributions with Application to North American BSE Announcements

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**with Application to North American BSE Announcements**

Options contain probabilistic information about the distribution of commodity prices and it is common practice to impute the volatility of commodity prices from observed trades in options markets. This is typically done by feeding options premiums into an option pricing model (e.g., Black-Scholes-Merton) to solve for price volatility. Notably, these implied volatilities (IVs) have been found to be superior to historical volatility (e.g. rolling window standard deviation of daily price log-changes) as a predictor of future volatility in commodity markets (Egelkraut, Garcia, and Sherrick; Poon and Granger).

Given this, it is curious that more has not been done within the agricultural economics profession to more fully exploit information that can be uncovered from options prices or to adopt alternative methods of deriving volatility and other characteristics of commodity price distributions from options premia. A large literature in financial economics has examined IVs derived from the prices of financial assets and has shown that implied volatilities differ across strike prices, giving rise to what are commonly called volatility smiles or smirks. As noted by Hull, implied volatilities recovered from foreign currency options tend to exhibit a smile pattern where both out-of-the-money (OTM) puts and calls return higher IVs than those that are near the money. In contrast, equity options tend to exhibit a leftward smirk pattern with OTM put options returning markedly higher IVs than call options that are similarly out of the money. The observed relationship between IV and moneyness suggests that markets for options are either inefficient or that the distributional assumptions underpinning the Black-Scholes-Merton model and its variants are incorrect (Rubinstein). A related literature has focused on uncovering implied pricing density functions empirically using observed options premia across different strike prices (see Breeden and Litzenberger; Rubinstein). Recently, Bakshi, Kapadia, and Madan demonstrate how to uncover volatility, skewness and kurtosis from options prices without assuming any specific pricing model. Skewness and kurtosis, in particular, are of interest if the underlying pricing distribution violates normality assumptions.

In this paper, we characterize the behavior of the IV surface for live cattle futures prices. Our first objective is to determine whether the volatility surface exhibits a smile, smirk or other persistent pattern found to be present in other market settings. To do this, we analyze the April 1985 through February 2008 live cattle futures and options contracts. We first compute IVs across strike prices and estimate the slope of the volatility surface by regressing IVs on degree of moneyness. Secondly, using methods developed by Bakshi, Kapadia, and Madan we compute implied skewness measures as an additional means of characterizing the volatility surface. A negative (positive) skewness of the pricing density function would be indicative of a leftward (rightward) smirk pattern in the volatility surface. Results from each approach show a distinct leftward smirk pattern in the pricing density of the vast majority of live cattle contracts over the period studied.

Our second objective is to show how additional information about the pricing density can be used to infer market responses to changing economic information. Specifically, we examine changes in the magnitude of skewness surrounding the initial announcements of Bovine Spongiform Encephalopathy (BSE) in North America that occurred in May and December of 2003. These events have been widely studied and their impact on prices and trade flows has been well documented (Jin, Power, and Elbakidze; Marsh, Brester, and Smith; Devadoss et al.; Coffey et al.). In addition, these events provide a good setting to illustrate how different moments of the pricing density are impacted by the potential for and occurrence of a major market disruption. Following the May 20, 2003 discovery of a BSE infected cow in Canada, cross border shipment of cattle and meat from Canada to the US was disrupted. In addition, Canadian exporters lost access to overseas markets in which they were previously competitive with US exporters. This chain of events raised US cattle prices, but the discovery of BSE in North America was unsettling, to say the least. Consequently, one would expect to have observed an increase in US live cattle price volatility and possibly an amplification of the leftward skew of the pricing density to reflect the very real possibility that a similarly infected animal could show up in a US herd. Indeed, on December 23, 2003 such an animal was discovered, and US live cattle prices fell precipitously. Like their Canadian counterparts, access of US exporters to foreign markets was restricted. Once again, the expected outcome of the US event would be an increase in price volatility given the uncertainty created about future market conditions. However, if the market had already priced the potential for a negative event of this magnitude into options premia, the skew should accordingly have become less pronounced to reflect the realization of the event.

Our results are largely consistent with this line of thought. They show significant increases in US cattle price volatility following both the May 20th and December 23rd events. Although there is little evidence of a shift in skewness following the May 20th event, the skew is much less pronounced for up to two months after the December 23rd event. At the lower cattle prices, the value of risk protection afforded by deep OTM put options appears to have declined relative to their at-the-money counterparts. In some respects, the response is a reversal of the “crash-o-phobia” phenomenon documented by Rubinstein following the stock market crash of 1987. Rubinstein shows that leftward smirks in S&P 500 options became more prevalent after the market crash and argues that the crash sensitized equity investors to the potential for large and adverse price moves thereby increasing the insurance premium reflected in deep OTM put options.

**Methods and Data**

Bakshi and Madan provide a general approach to valuing contracts with payoffs conditional on the value of the price of an asset at some future time period. Let s be the price of an asset at the terminal time period T and let H[s] be the payoff as a function of the terminal asset price. Bakshi and Madan show that if H[s] is continuous and twice differentiable then the payoff can be spanned algebraically as:

(1) $H[s] = H[\bar{s}] + (s - \bar{s})H'[\bar{s}] + \int_{\bar{s}}^{\infty} H''[k]\, max[s-k, 0]\, dk + \int_0^{\bar{s}} H''[k]\, max[k-s, 0] dk$

where $\bar{s} > 0$ is an arbitrary value. Let q[s] be the risk-neutral pricing density function. Note that at the current time t and with τ = (T - t) years, the value of European call and put options with strike price k can be defined in terms of the density function, respectively, as

(2) $C[\tau, k] = \int_0^{\infty} e^{-r\tau} max[s-k, 0] q[s] ds$

and

(3) $P[\tau, k] = \int_0^{\infty} e^{-r\tau} max[k-s, 0] q[s] d\, s$

where r is the risk-free rate. Using these definitions, Bakshi, Kapadia, and Madan price the payoff function by discounting equation (1) and taking its risk neutral expectation to obtain

(4) $p\big[H[s]\big] = e^{-r\tau}(H[\bar{s}] - \bar{s}\, H'[\bar{s}]) + H'[\bar{s}]s_t + \int_{\bar{s}}^{\infty} H''[k] C[\tau, k]\, dk + \int_0^{\bar{s}} H''[k] P[\tau, k] dk$

The significance of equation (4) is twofold. First, H[s] can be replicated by three positions in market-traded assets. Specifically these consist of a position of $H[\bar{s}] - \bar{s}\, H'[\bar{s}]$ in a treasury bond, a position of $H'[\bar{s}]$ in the underlying asset, and a portfolio of OTM calls and puts that is weighted by the $H''[k]$ terms. Second, no specific distribution need be assumed in order to price the contract.

Bakshi, Kapadia, and Madan show how to use equations (1) and (4) to uncover higher moments of the risk-neutral price distribution. In doing so they define payoff functions $\ln[s/s_t]^2$, $\ln[s/s_t]^3$, and $\ln[s/s_t]^4$, which they term volatility, cubic, and quartic contracts, respectively. They then price these contracts using equation (4) and substitute the arbitrage free price $s_t$ for $\bar{s}$ to obtain prices of

(5) $V[\tau] = \int_{s_t}^{\infty} \frac{2(1 - \ln[k/s_t])}{k^2} C[\tau, k]\, dk + \int_0^{s_t} \frac{2(1 + \ln[s_t/k])}{k^2} P[\tau, k] dk$

for the volatility contract,

(6) $W[\tau] = \int_{s_t}^{\infty} \frac{6 \ln\left[\frac{k}{s_t}\right] - 3\left(\ln\left[\frac{k}{s_t}\right]\right)^2}{k^2} C[\tau, k]\, dk - \int_0^{s_t} \frac{6\ln[s_t/k] + 3(\ln[s_t/k])^2}{k^2} P[\tau, k] dk,$

for the cubic contract, and

(7) $X[\tau] = \int_{s_t}^{\infty} \frac{12\left(\ln\left[\frac{k}{s_t}\right]\right)^2 - 4\left(\ln\left[\frac{k}{s_t}\right]\right)^3}{k^2} C[\tau, k]\, dk + \int_0^{s_t} \frac{12(\ln[s_t/k])^2 + 4(ln\,[s_t/k])^3}{k^2} P[\tau, k] dk$

for the quartic contract. Note that each represents a portfolio of OTM put and call options. Selected moments of the risk-neutral price distribution in terms of these contract prices are computed as follows:

(8) $Mean[\tau] = e^{r\tau} - 1 - \frac{e^{r\tau}}{2} V[\tau] - \frac{e^{r\tau}}{6} W[\tau] - \frac{e^{r\tau}}{24} X[\tau],$

(9) $Variance[\tau] = e^{r\tau} V[\tau] - Mean[\tau]^2,$

(10) $Skew[\tau] = \frac{e^{r\tau} W[\tau] - 3e^{r\tau} Mean[\tau] V[\tau] + 2\, Mean[\tau]^3}{(e^{r\tau} V[\tau] - Mean[\tau]^2)^{3/2}},$

In our analysis, two approaches are used to characterize the volatility surface. First, for each non-limit trading day, Black's options pricing model was used to compute an implied volatility measure at each strike price on each traded contract. Using OTM put and call options, the model in equation (11) was used to estimate the slope of the resulting volatility surfaces.

(11) $IV_{it} = \alpha_t + \beta_t \ln[k_{it}/s_t] + \varepsilon_t,$

where i indexes the strike prices, t indexes the day, $s_t$ is settle price for the live cattle futures contract, and $\varepsilon_t$ is an error term. Not that if the IVs derived from OTM put options are higher (lower) than IVs derived from OTM call options, then the estimate of $\beta_t$ will be negative (positive) which indicates a leftward (rightward) skew to the volatility surface or equivalently that put options were expensive (inexpensive) relative to calls. Second, model-free measures of volatility and skewness based on equation (9) and (10) were computed for each non-limit trading day on which premiums for at least two OTM puts and two OTM call options were observed. In computing these measures, equations (5), (6), and (7) were approximated by numerically integrating over observed OTM options premia. Specifically, let i = 1, 2, … m index the strikes on OTM put options and i = m+1, m+2, … N index the strikes on OTM call options. Moreover, let the observations be ordered by strike price so that $k_1 < k_2 < \ldots k_N$. First we weighted each observed premium by the second derivative of the payoff under each contract. This provides $V_i[\tau]$, $W_i[\tau]$, and $X_i[\tau]$ as follows:

(12a) $V_i[\tau] = \frac{2\left(1+\ln\left[\frac{s_t}{k_i}\right]\right)}{k_i^2} P[\tau, k_i]$ for $i = 0, \cdots, m$

(12b) $V_i[\tau] = \frac{2\left(1-\ln\left[\frac{k_i}{s_t}\right]\right)}{k_i^2} C[\tau, k_i]$ for $i = m+1, \cdots, N$

(13a) $W_i[\tau] = -\frac{6\ln\left[\frac{s_t}{k_i}\right]+3(\ln\left[\frac{s_t}{k_i}\right])^2}{k_i^2} P[\tau, k_i]$ for $i = 1, \cdots, m$

(13b) $W_i[\tau] = \frac{6\ln\left[\frac{k_i}{s_t}\right]-3(\ln\left[\frac{k_i}{s_t}\right])^2}{k_i^2} C[\tau, k_i]$ for $i = m+1, \cdots, N$

(14a) $X_i[\tau] = \frac{12(\ln\left[\frac{s_t}{k_i}\right])^2+4(\ln\left[\frac{s_t}{k_i}\right])^3}{k_i^2} P[\tau, k_i]$ for $i = 1, \cdots, m$

(14b) $X_i[\tau] = \frac{12(\ln\left[\frac{k_i}{s_t}\right])^2-4(\ln\left[\frac{k_i}{s_t}\right])^3}{k_i^2} C[\tau, k_i]$ for $i = m+1, \cdots, N$

Using the trapezoidal rule for numeric integration, the price of each contract is then computed as:

(15) $V[\tau] = \frac{1}{2}\sum_{i=2}^{N}(V_i[\tau] + V_{i-1}[\tau])(k_i - k_{i-1})$

(16) $W[\tau] = \frac{1}{2}\sum_{i=2}^{N}(W_i[\tau] + W_{i-1}[\tau])(k_i - k_{i-1})$

(17) $X[\tau] = \frac{1}{2}\sum_{i=2}^{N}(X_i[\tau] + X_{i-1}[\tau])(k_i - k_{i-1})$

Historic closing options premia and settlement prices for live cattle futures prices were purchased from Bridge CRB. The dataset covers the April 1985 through February 2008 live cattle contracts. The yield on 6-month treasury bills was used for the discount rate in all options pricing formulae. There are, on occasion, some anomalies with the data. For example, there are a few occasions where reported options premia are less than the intrinsic value of the option given the reported settlement price. These types of problems, although few in comparison to the size of the dataset, are more prevalent when time to option expiration is very distant or as expiration dates approach and can most likely attributed to stale options prices and other liquidity related problems. Consequently, we summarize and report findings for a period of roughly 18 to 2 weeks prior to the date of option expiration on each contract.

We conduct a simple event study to assess behavior of volatility and skewness in live prices around the BSE announcements that occurred in 2003. First, we use two months of trading activity to establish a mean for both IV and skewness. Second, we construct a confidence interval about a forecast from this mean, which is then used to assess the significance of post-event levels of both IV and skewness.

**Volatility Surface Results**

Table 1 shows estimates of volatility slopes ($\beta_t$ equation 11) for our 1985 – 2008 sample period. The results are presented with respect to minimum, average and maximum slope estimates across years and contract months. In general, slope estimates are negative irrespective of year or contract month, which is clearly indicative of a persistent leftward skew or smirk pattern in the volatility surface. In the early period of the sample (contracts maturing before 1988-89), there was less evidence of this pattern. The pattern was also less pronounced for the December 1997 through October 1998 contracts. Table 2 presents a summary of the model-free implied skewness measures. By and large, the results in table 2 are consistent with those in table 1. Again these measures suggest the pricing density was generally skewed to the left. Interestingly, most of the maximum values for skewness reported in table 2 are negative. The main conclusion that can be drawn from tables 1 and 2 is that over most of the period analyzed puts were more expensive than calls that were similarly out of the money. In other words, there tended to be more probability mass in the left tail of the pricing density than would be expected under assumptions of normality.

**Market Responses to BSE Events**

Model-free measures of volatility and skewness are presented in figures 1- 4 for the nearby contract and the next three nearest to maturity contracts for the time surrounding the May 20, 2003 and December 23, 2003 BSE announcements. IVs derived from at-the-money options from Black's model (not shown) were nearly identical to the model-free measures illustrated in figures 1 and 3. As shown in figure 1, there was an immediate increase in IV for all contract months after the Canadian discovery. Furthermore the increase in volatility is generally well outside a 99 percent confidence band. The only exception is two observations from the June contract. On May 20th, options on the June contract were nearing expiration and the confidence interval for IV was relatively large. For all other contracts volatility remained high for the two months following the event. The spike in IV is consistent with greater uncertainty about future US live cattle price levels that resulted from the Canadian BSE event and ensuing market disruptions.

Interestingly, however, there is little evidence that the pricing density became more skewed following the Canadian announcement. Figure 2 shows post-event levels of skewness that are generally in-line with pre-event levels. Based on the implied skew, outlook for prices of the nearby June 2003 contract did become more skewed after the event, but again, options on this contract were nearing expiration and the increase in skewness does not appear to have been an immediate consequence of the event. There is no evidence of the sharp and immediate response analogous to that which was observed in the IV measures shown in figure 1. Towards the end of the two-month event window, the implied skewness on the October contract fell outside the 99 percent confidence interval, however, it would be a stretch to suggest that this increase in skewness was a direct consequence of the May 20th event.

Turning now to the December 23rd discovery of BSE in the US, figure 3 shows an abrupt and large increase in IV following the announcement. The magnitude of the IV increase is over 100 percent for the nearby February 2004 contract and is among the largest IV measures observed over the entire 1985 to 2008 period. Although there was an immediate and sharp increase in IV for all contracts, IV fell slightly over the next few non-limit trading days. However, IV levels remained high and did not fall within the 99 percent confidence interval of pre-event levels during the following two-months. Again, this increase in IV is consistent with higher levels of uncertainty in cattle markets. Most interestingly and in contrast to the Canadian event, the implied skewness measures in figure 4 indicate a definite event-related shift. In particular, the degree of skewness dropped markedly in all contracts. What this indicates is that after the event, there was substantially less probability mass in the left tail of the pricing density.

These results are largely as would be expected. Both events created significant disruptions to trade flows and created considerable market uncertainty and implied volatility levels jumped in response. In other words, options became more expensive as the insurance they provide became more valuable. The more interesting findings, however, are with respect to the change in implied skewness attributed to these events. Following the US announcement, the pricing density exhibited much less skewness. This would indicate that prior to the BSE event the market had already priced a potential large negative price shock into options premia. Given the immediate and significant reduction in skewness, it may not be too much of a stretch to argue that the market had specifically priced in the potential for a US BSE event and its attendant consequences. However, if this is the case, it might have been expected that the degree of skewness in the US pricing density should have increased after the Canadian announcement as this announcement made abundantly clear that the US cattle industry was susceptible to the disease.

**Discussion**

Much more could be learned about the behavior of commodity prices by taking advantage of developments in financial economics to extract additional information about the pricing density implied by options premia. In this paper we characterized the volatility surface for live cattle and conducted a simple event study around the two initial North American BSE events. These events provided a good setting within which to show how additional information about the pricing density can be used to infer market responses to changing economic information.

This paper raises some additional research questions. First, there is strong evidence of a leftward smirk associated with the vast majority of live cattle contracts between April 1985 and through February 2008. A natural question is why the persistent skew? This question might be answered by examining other commodities to determine whether such a skew prevails in other markets or whether it is unique to live cattle. Furthermore, can differences in the patterns of the skew across commodities or over time be attributed to characteristics of market structure or to changes in structural characteristics over time? Answers to these questions would advance our understanding of price discovery in agricultural commodity markets and would likely improve marketing and risk management practices.

Secondly, higher moments of the pricing density could be analyzed to gain useful insight into the behavior of markets around a variety of events. While mean and volatility responses are commonly assessed to determine the informational content of events, event induced changes to implied skews may reveal additional information about market sentiment or help qualify conclusions drawn from responses in mean price levels. While we did not specifically examine implied kurtosis, model-free methods can be used to estimate that as well. In future studies, changes to implied kurtosis can also be used to assess whether the occurrence of events changes the likelihood of extreme price moves.

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**Table 1. Slopes of the volatility surface computed over OTM options, live cattle contracts 18 to 2 weeks prior to option expiration**

| | February | | | April | | | June | | | August | | | October | | | December | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Year | min | mean | max | min | mean | max | min | mean | max | min | mean | max | min | mean | max | min | mean | max |
| 1985 | | | | -0.34 | 0.02 | 0.59 | -0.57 | 0.00 | 0.21 | -0.34 | 0.01 | 0.26 | -0.20 | 0.04 | 0.34 | -0.65 | -0.15 | 0.10 |
| 1986 | -0.35 | -0.09 | 0.20 | -0.17 | -0.01 | 0.14 | -0.22 | 0.00 | 0.14 | -0.29 | 0.01 | 0.16 | -0.34 | -0.05 | 0.07 | -0.21 | -0.05 | 0.02 |
| 1987 | -0.52 | -0.06 | 0.05 | -0.25 | -0.04 | 0.21 | -0.42 | -0.09 | 0.05 | -0.36 | -0.13 | 0.04 | -0.40 | -0.08 | 0.04 | -0.25 | -0.07 | 0.10 |
| 1988 | -0.36 | -0.05 | 0.10 | -0.30 | -0.12 | 0.00 | -0.62 | -0.24 | -0.04 | -0.41 | -0.23 | -0.04 | -0.62 | -0.22 | 0.01 | -0.49 | -0.27 | -0.14 |
| 1989 | -0.47 | -0.23 | -0.01 | -0.44 | -0.22 | -0.04 | -0.33 | -0.15 | 0.28 | -0.25 | -0.04 | 0.13 | -0.38 | -0.15 | 0.30 | -0.45 | -0.20 | 0.02 |
| 1990 | -0.46 | -0.27 | -0.08 | -0.63 | -0.32 | -0.08 | -0.47 | -0.25 | -0.05 | -0.58 | -0.31 | -0.15 | -0.46 | -0.31 | -0.09 | -0.64 | -0.28 | -0.14 |
| 1991 | -0.71 | -0.27 | -0.15 | -0.82 | -0.37 | -0.19 | -0.67 | -0.35 | -0.17 | -0.55 | -0.29 | 0.05 | -0.85 | -0.31 | 0.03 | -0.63 | -0.29 | -0.03 |
| 1992 | -0.69 | -0.36 | -0.19 | -0.53 | -0.35 | -0.16 | -0.51 | -0.34 | 0.04 | -0.56 | -0.28 | -0.16 | -0.97 | -0.40 | -0.16 | -0.78 | -0.41 | -0.22 |
| 1993 | -0.62 | -0.29 | -0.19 | -0.89 | -0.30 | -0.13 | -0.41 | -0.22 | -0.01 | -0.47 | -0.28 | 0.09 | -0.63 | -0.24 | -0.05 | -0.48 | -0.22 | -0.13 |
| 1994 | -0.24 | -0.12 | 0.18 | -0.59 | -0.23 | -0.10 | -0.49 | -0.24 | 0.15 | -0.67 | -0.17 | 1.85 | -0.52 | -0.27 | -0.07 | -0.51 | -0.22 | -0.05 |
| 1995 | -0.73 | -0.23 | -0.06 | -0.32 | -0.15 | 0.18 | -0.24 | -0.12 | 0.12 | -0.38 | -0.13 | 0.04 | -0.47 | -0.30 | 0.00 | -0.78 | -0.38 | -0.25 |
| 1996 | -0.35 | -0.20 | 0.11 | -0.31 | -0.12 | 0.34 | -0.49 | -0.19 | -0.05 | -0.78 | -0.36 | -0.16 | -1.05 | -0.46 | -0.27 | -0.39 | -0.24 | -0.06 |
| 1997 | -0.29 | -0.13 | 0.30 | -0.40 | -0.24 | 0.07 | -0.30 | -0.14 | 0.08 | -0.61 | -0.22 | -0.04 | -0.68 | -0.27 | 0.05 | -0.29 | -0.10 | 0.24 |
| 1998 | -0.50 | -0.07 | 0.21 | -0.48 | -0.06 | 0.13 | -0.34 | -0.10 | 0.29 | -0.50 | -0.02 | 0.51 | -0.53 | -0.02 | 0.21 | -0.49 | -0.24 | 0.10 |
| 1999 | -0.49 | -0.25 | 0.09 | -0.54 | -0.31 | -0.08 | -0.45 | -0.24 | 0.22 | -0.63 | -0.27 | -0.07 | -0.69 | -0.33 | -0.19 | -0.54 | -0.32 | 0.01 |
| 2000 | -0.41 | -0.26 | -0.03 | -0.76 | -0.29 | -0.10 | -0.38 | -0.20 | 0.13 | -0.33 | -0.14 | 0.28 | -0.38 | -0.08 | 0.27 | -0.51 | -0.13 | 0.09 |
| 2001 | -0.83 | -0.27 | -0.08 | -0.77 | -0.37 | -0.17 | -0.78 | -0.44 | -0.18 | -0.80 | -0.44 | 0.04 | -0.43 | -0.31 | 0.05 | -0.53 | -0.21 | 0.09 |
| 2002 | -0.59 | -0.23 | -0.04 | -0.67 | -0.35 | 0.27 | -0.39 | -0.19 | 0.47 | -0.72 | -0.13 | 0.15 | -0.85 | -0.34 | -0.13 | -1.30 | -0.49 | -0.24 |
| 2003 | -0.95 | -0.57 | -0.35 | -0.63 | -0.47 | -0.07 | -0.90 | -0.43 | -0.24 | -0.84 | -0.38 | -0.17 | -0.90 | -0.52 | -0.19 | -0.70 | -0.50 | -0.26 |
| 2004 | -0.60 | -0.36 | -0.01 | -0.63 | -0.23 | 0.01 | -1.03 | -0.36 | -0.01 | -0.78 | -0.45 | -0.16 | -0.79 | -0.45 | -0.31 | -0.92 | -0.43 | -0.26 |
| 2005 | -0.58 | -0.43 | -0.19 | -0.83 | -0.40 | -0.17 | -1.09 | -0.44 | -0.13 | -0.87 | -0.44 | -0.25 | -0.74 | -0.36 | -0.21 | -0.80 | -0.44 | -0.22 |
| 2006 | -1.05 | -0.52 | -0.35 | -0.63 | -0.43 | -0.19 | -0.41 | -0.14 | 0.17 | -0.77 | -0.27 | 0.03 | -0.63 | -0.35 | 0.13 | -0.65 | -0.33 | -0.06 |
| 2007 | -0.89 | -0.44 | -0.25 | -1.07 | -0.52 | -0.29 | -0.75 | -0.46 | -0.31 | -0.54 | -0.40 | -0.30 | -0.73 | -0.42 | -0.25 | -0.53 | -0.32 | -0.08 |
| 2008 | -0.45 | -0.33 | 0.21 | -0.41 | -0.24 | 0.43 | -0.41 | -0.20 | 0.06 | | | | | | | | | |

**Table 2. Implied skewness, live cattle contracts on non-limit trading days 18 to 2 weeks prior to option expiration**

| | February | | | April | | | June | | | August | | | October | | | December | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Year | min | mean | max | min | mean | max | min | mean | max | min | mean | max | min | mean | max | min | mean | max |
| 1985 | | | | -2.08 | -1.08 | -0.07 | -2.12 | -1.04 | -0.05 | -2.37 | -0.90 | 0.63 | -1.07 | -0.33 | 0.66 | -1.52 | -0.77 | 0.45 |
| 1986 | -1.27 | -0.84 | 0.01 | -1.03 | -0.43 | 0.13 | -1.02 | -0.35 | 0.48 | -0.52 | -0.10 | 0.61 | -0.77 | -0.33 | 0.39 | -0.86 | -0.54 | -0.15 |
| 1987 | -0.99 | -0.59 | -0.18 | -1.16 | -0.68 | 0.02 | -1.27 | -0.69 | -0.22 | -1.12 | -0.77 | -0.27 | -1.10 | -0.72 | -0.44 | -1.29 | -0.81 | -0.02 |
| 1988 | -1.56 | -0.64 | -0.09 | -1.11 | -0.71 | -0.41 | -1.71 | -1.07 | -0.60 | -1.77 | -1.25 | -0.40 | -2.26 | -1.15 | -0.41 | -2.88 | -1.54 | -0.86 |
| 1989 | -1.73 | -1.34 | -0.59 | -2.01 | -1.47 | -0.58 | -2.86 | -1.52 | -0.41 | -2.49 | -1.19 | -0.32 | -2.28 | -1.46 | -0.24 | -2.40 | -1.63 | -0.73 |
| 1990 | -2.84 | -2.01 | -0.98 | -2.95 | -2.06 | -0.69 | -2.55 | -1.90 | -0.59 | -3.47 | -2.22 | -0.96 | -3.30 | -2.17 | -0.63 | -3.87 | -1.97 | -0.82 |
| 1991 | -2.86 | -1.77 | -0.67 | -2.95 | -2.03 | -0.74 | -2.91 | -1.94 | -0.83 | -3.08 | -1.85 | -0.49 | -2.98 | -1.64 | -0.09 | -3.24 | -1.51 | -0.63 |
| 1992 | -2.58 | -1.67 | -0.57 | -1.93 | -1.32 | -0.58 | -2.13 | -1.47 | -0.13 | -1.69 | -1.26 | -0.50 | -2.22 | -1.54 | -1.12 | -2.17 | -1.62 | -0.83 |
| 1993 | -1.77 | -1.26 | -0.71 | -1.90 | -1.26 | -0.63 | -1.56 | -1.04 | -0.18 | -1.88 | -1.26 | -0.12 | -1.51 | -1.03 | -0.47 | -1.57 | -0.96 | -0.49 |
| 1994 | -1.23 | -0.67 | -0.22 | -1.20 | -0.96 | -0.74 | -2.03 | -1.26 | -0.01 | -2.01 | -0.91 | 2.61 | -1.86 | -0.99 | -0.36 | -1.77 | -1.03 | -0.50 |
| 1995 | -2.19 | -1.11 | -0.76 | -2.01 | -1.19 | -0.05 | -1.83 | -0.95 | -0.10 | -1.11 | -0.65 | 0.24 | -1.78 | -1.23 | -0.39 | -1.97 | -1.59 | -0.66 |
| 1996 | -2.10 | -1.28 | -0.19 | -1.86 | -0.92 | 0.18 | -1.30 | -0.89 | 0.28 | -2.00 | -1.16 | -0.36 | -2.67 | -1.86 | -1.35 | -1.88 | -1.24 | -0.25 |
| 1997 | -1.45 | -0.81 | 0.40 | -1.74 | -1.06 | -0.21 | -1.69 | -1.04 | -0.39 | -1.83 | -1.20 | -0.50 | -1.99 | -1.37 | -0.25 | -2.16 | -1.02 | 0.00 |
| 1998 | -1.69 | -0.77 | -0.01 | -1.94 | -0.66 | 0.12 | -1.21 | -0.77 | 0.01 | -1.45 | -0.73 | 0.72 | -1.52 | -0.50 | 0.30 | -1.60 | -0.85 | -0.31 |
| 1999 | -1.42 | -0.77 | 0.03 | -1.35 | -0.86 | -0.25 | -1.55 | -1.01 | -0.14 | -1.77 | -1.10 | -0.59 | -1.80 | -1.30 | -0.13 | -2.13 | -1.39 | -0.24 |
| 2000 | -2.15 | -1.29 | -0.41 | -1.93 | -1.41 | -0.68 | -2.29 | -1.40 | -0.40 | -2.16 | -1.34 | -0.15 | -2.02 | -1.22 | -0.08 | -2.18 | -1.25 | -0.69 |
| 2001 | -2.22 | -1.65 | -0.74 | -3.09 | -1.70 | -0.66 | -2.20 | -1.63 | -0.60 | -2.14 | -1.59 | -0.30 | -1.92 | -1.31 | -0.17 | -1.86 | -0.96 | 0.02 |
| 2002 | -1.12 | -0.74 | -0.19 | -2.03 | -1.19 | 0.16 | -1.97 | -1.01 | 0.51 | -1.35 | -0.53 | 0.35 | -1.71 | -1.18 | -0.47 | -2.49 | -1.58 | -0.98 |
| 2003 | -3.08 | -2.08 | -0.69 | -2.59 | -1.75 | -0.40 | -1.70 | -1.23 | -0.67 | -1.85 | -1.12 | -0.56 | -2.46 | -1.49 | -0.52 | -2.70 | -1.70 | -0.95 |
| 2004 | -1.98 | -1.27 | -0.27 | -1.23 | -0.65 | 0.07 | -2.46 | -0.99 | 0.00 | -2.00 | -1.33 | -0.52 | -1.91 | -1.41 | -0.95 | -2.07 | -1.52 | -0.96 |
| 2005 | -1.94 | -1.35 | -0.25 | -2.18 | -1.25 | -0.69 | -3.04 | -1.61 | -0.72 | -2.74 | -1.73 | -1.09 | -1.98 | -1.45 | -0.95 | -2.37 | -1.72 | -0.71 |
| 2006 | -2.76 | -2.11 | -1.20 | -2.80 | -1.93 | -0.74 | -2.29 | -1.01 | 0.02 | -2.28 | -1.08 | -0.24 | -2.67 | -1.47 | -0.15 | -2.08 | -1.44 | -0.70 |
| 2007 | -2.00 | -1.62 | -1.19 | -3.15 | -2.05 | -1.11 | -3.52 | -1.94 | -1.01 | -2.25 | -1.58 | -0.63 | -2.67 | -1.78 | -0.75 | -2.60 | -1.72 | -0.73 |
| 2008 | -2.33 | -1.53 | -0.28 | -2.08 | -1.15 | 0.41 | -1.16 | -0.62 | 0.10 | | | | | | | | | |

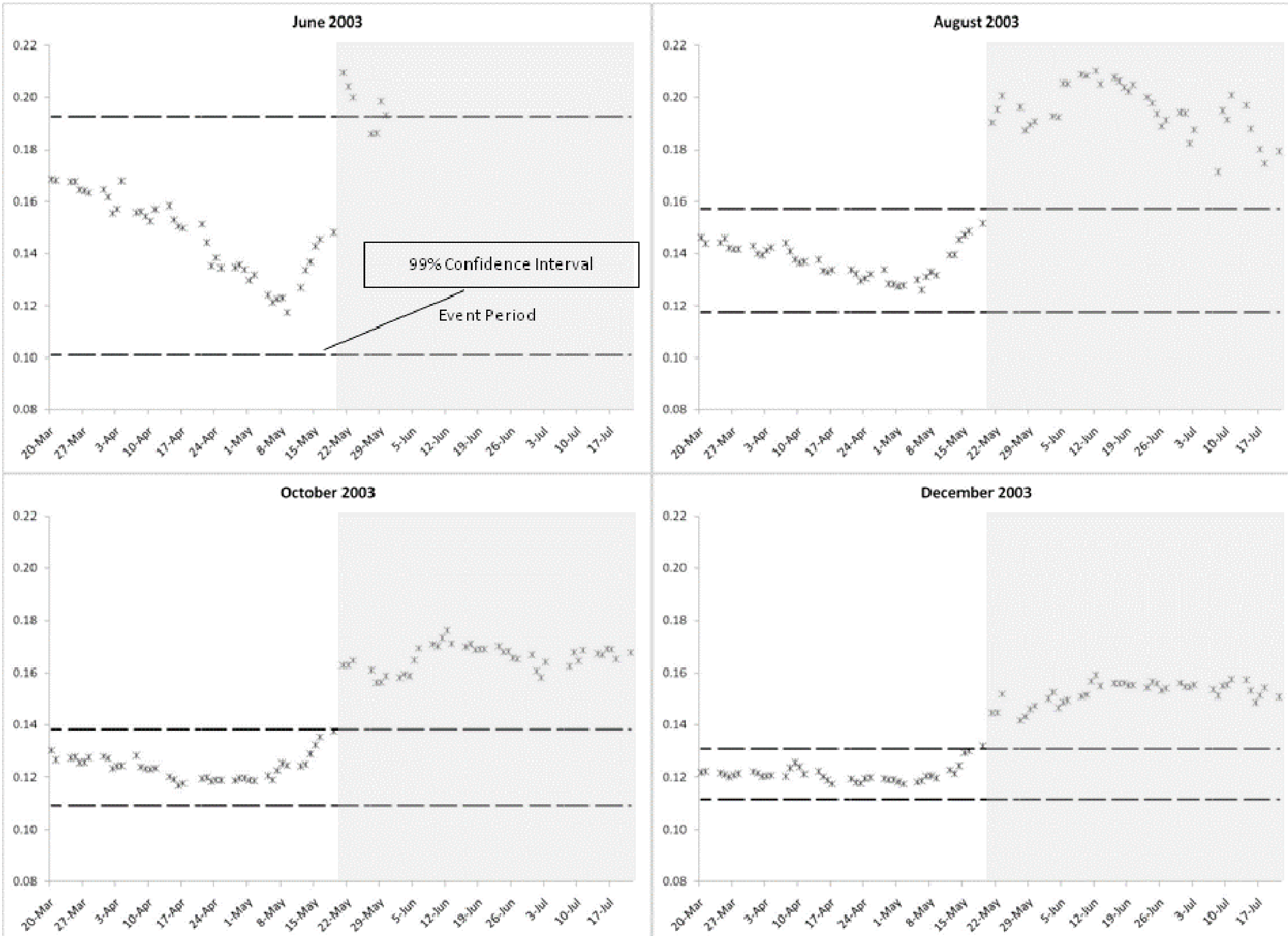


**Figure 1. Implied volatility of US live cattle futures prices around the May 20, 2003 announcement of BSE in Canada, by contract.**

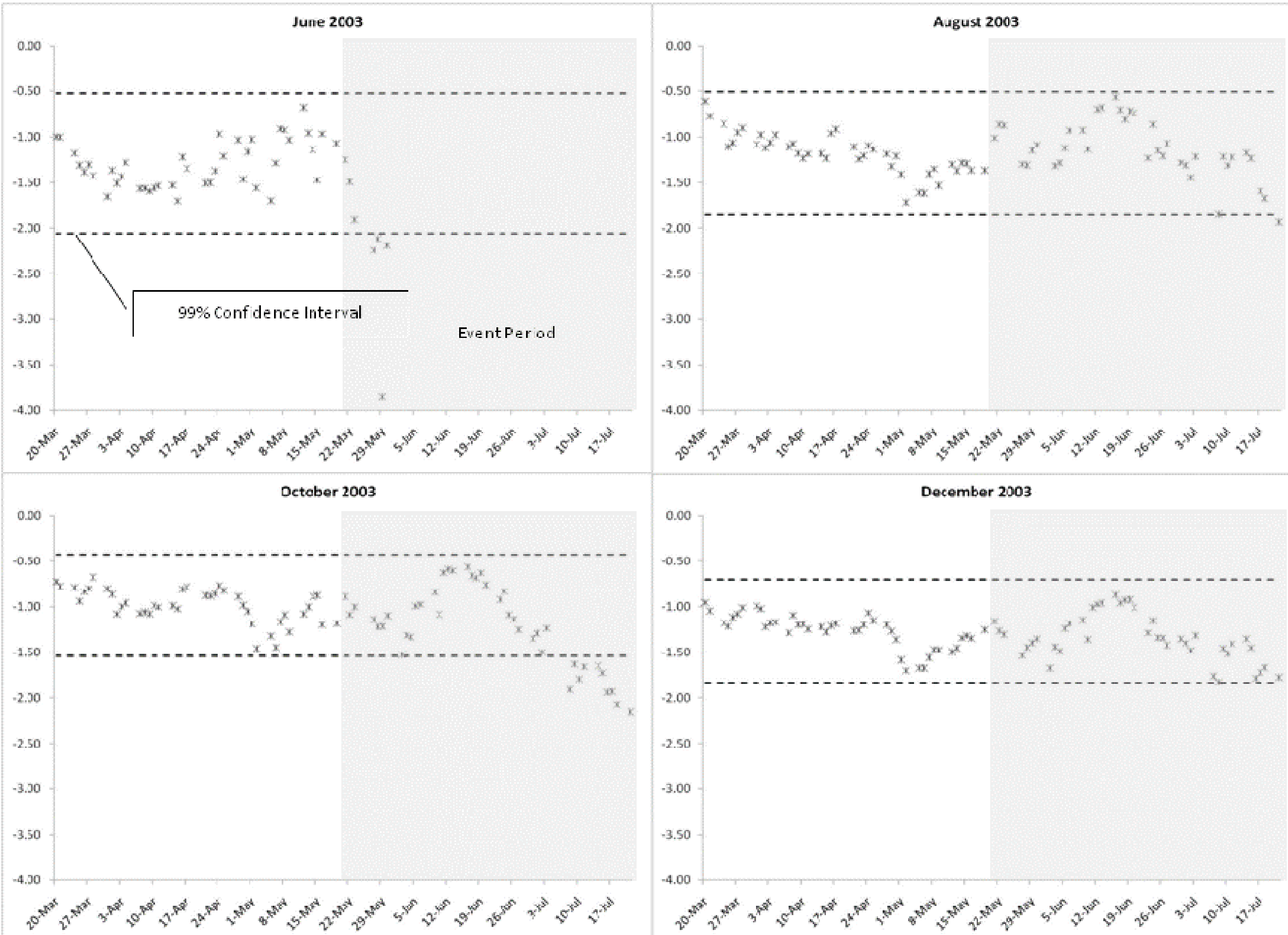


**Figure 2. Implied skewness of US live cattle futures prices around the May 20, 2003 announcement of BSE in Canada, by contract.**

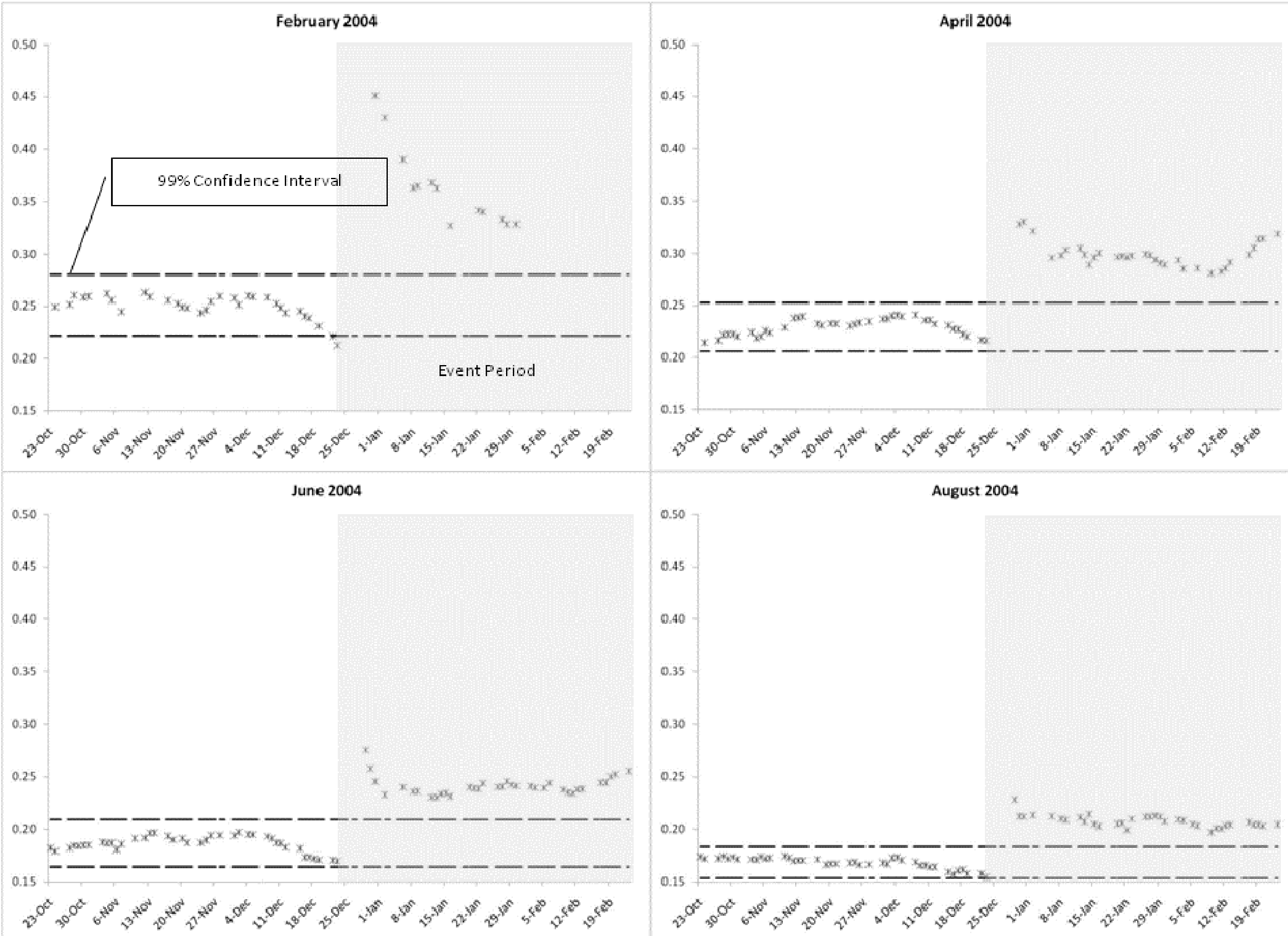


**Figure 3. Implied volatility of US live cattle futures prices around the December 23, 2003 announcement of BSE in the USA, by contract.**

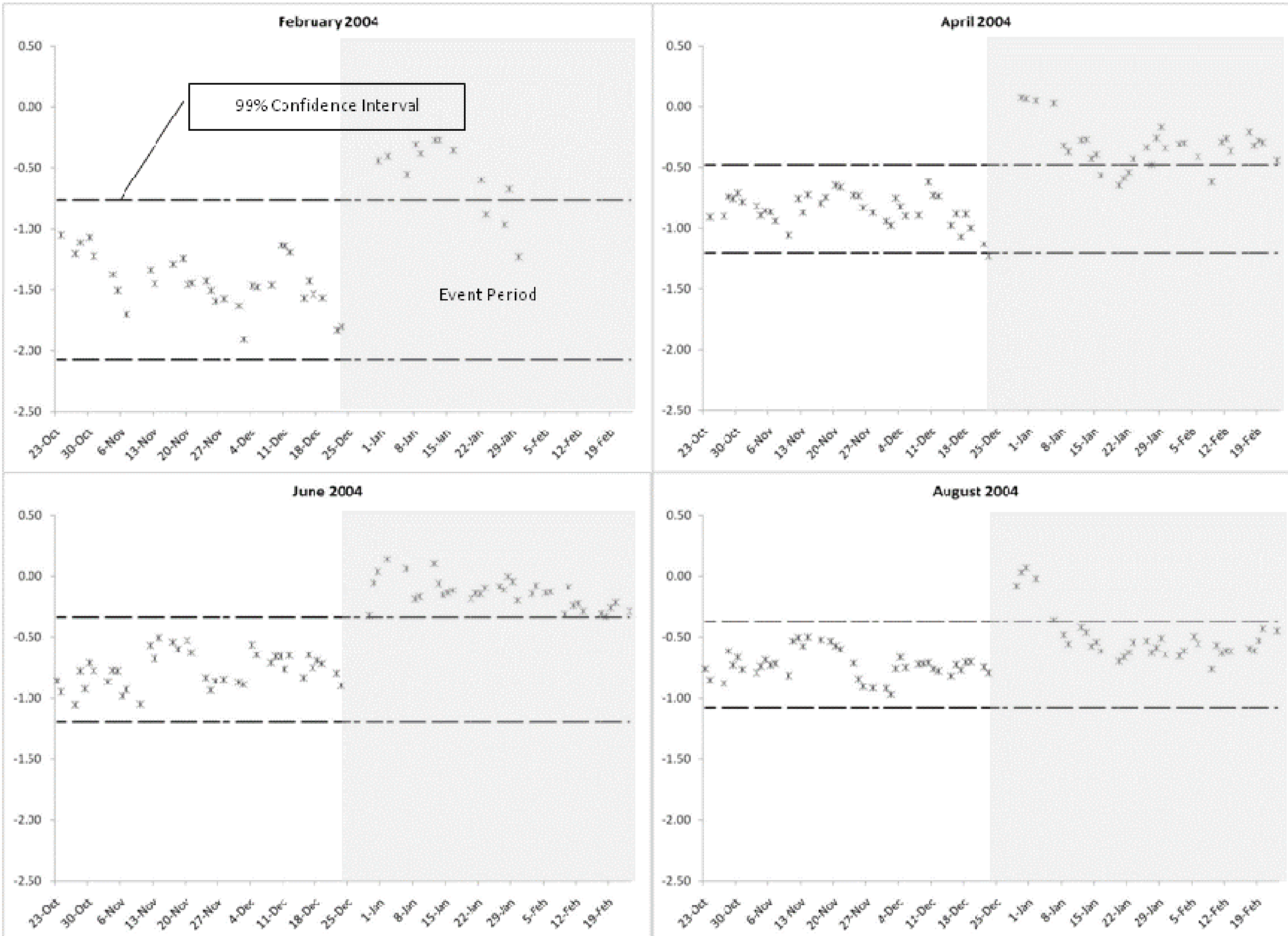


**Figure 4. Implied skewness of live cattle futures prices around the December 23, 2003 announcement of BSE in the USA.**