USE OF NYMEX FUTURES AND OPTIONS FOR EFFICIENT MARKET FORECASTS

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Certificate

This is to certify that the dissertation on "USE OF NYMEX FUTURES AND OPTIONS FOR EFFICIENT MARKET FORECASTS" submitted to the University of Petroleum and Energy Studies, Gurgaon by Sumit Varshney (R N0) in partial fulfillment of the requirement for the award of the degree of M.S (Oil Trading) is a bonafide work carried out by him under my supervision and guidance.

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Acknowledgement

"When the glaciers melt in the mountains they form streams. These streams are overflowing with energy as they seek out their paths from amongst the mountains. They may cause a lot of noise falling from great height. On the other hand, these ebullient streams might take form of deep, silent and rich rivers. The difference between these two is only that the later ones have banks on their either sides which guide their arduous journey through the mountainous terrain so that one day the river reaches its destination - the ocean".

The metaphor is highly relevant in the context of dissertation of mine, as I too felt like a stream, which would have been without directions had it not been for my guiding banks.

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Sumit Varshney

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1 Purpose of Study

This study develops a method for estimating confidence intervals surrounding futures based forecasts of natural gas prices. The central model uses options based measures of the distribution from which future natural gas prices will be drawn to develop probabilistic expectations about the mean and standard deviation of a gas futures contract at expiration. These measures can help market participants (both financial and physical) develop realistic expectations about the range of possible price outcomes.

2 Introduction

Although current futures prices provide a forecast of market participants' price expectations for future dates, the price alone provides no information regarding the distribution of these price expectations. To gain more information, the historical standard deviation of futures prices could be measured and used to develop a probability (or confidence interval) surrounding the current futures price. This method is used by many market participants but it may not be the best method to take advantage of all the information present in the market. An alternative method is to use information contained in options prices to develop a measure of the futures price standard deviation. Efficient option prices should contain all available information - including costly information that may not be available to the casual user - including the distribution of expectations of future prices. Options traders must combine their assessments of the historical standard deviation with perceptions of future price movements to accurately price the option under consideration. A properly specified option pricing model can be used to extract the traders' expectations about future price movements.

This paper will first present a detailed discussion of the theory and intuition behind the pricing of options. This discussion is essential to understanding the option pricing models presented next and why the futures price standard deviation can be backed out of them. The first model discussed will apply to European options - options that can only be exercised on their final day of existence. Next, the pricing of American style options will be presented. These options can be exercised at any time until they expire and are the primary focus of this paper.

Once the method for backing the standard deviation out of the American model is presented, the paper outlines a method to weight and combine the standard deviations derived from several options on the same contract. The predictive power of this weighted standard deviation is then compared - through regression analysis - to the predictive power of the historical standard deviation. The paper then presents the method for producing a futures/options based forecast and presents evidence that the mean derived from the futures price and option implied standard deviation is a superior predictor of the futures price at contract expiration.

3 Option Pricing Theory

Options on natural gas futures contracts were first actively traded in the early 1990's. The most widely traded natural gas option is found on the New York Mercantile Exchange (NYMEX) and is based on Henry Hub natural gas futures contracts. Although these options are fairly new, the market is quite robust. Natural gas futures options can now be purchased on contracts expiring several years in the future. Most of the trading action, however, is centered on contracts near expiration (one to six months until expiration).

The gas futures options traded on the NYMEX are American style. Like all options, they give the owner the right but not the obligation to buy or sell a gas futures contract at a specified price (strike price). An American (as opposed to a European) "call" option gives the owner the right to purchase the underlying commodity for the strike price at any time until the option's expiration date. Conversely, a "put" option allows the owner to sell a commodity at a specific price at any time until expiration. A European option can only be exercised at expiration. If any of these options are not exercised, they will expire worthless.

As will be explained in detail, the main factors affecting prices of options on futures are the underlying price of the futures contract, the position of the strike price relative to the futures price, the risk free rate of interest, the time to the option's expiration, and the volatility of the underlying commodity. Throughout this paper these variables will be represented as follows:

r	risk free rate of interest
σ	annualized volatility of the asset price
S	underlying asset price
t	time remaining until the expiration of the option (years)
E	exercise price of the option

Therefore, the price of a call option is defined as:

$$C = C(S,E,t,r,\sigma)$$

In order to understand how options are priced we need to look at some basic concepts underlying their value. First, for any given expiration, the lower the strike price of the call, the higher the price of the option. Second, for options sharing the same asset and exercise price, the call option with the longest time until expiration will have the highest value. Third, for call options on the same asset with the same remaining life, options with lower exercise prices will have higher values. To understand the relationship between the five variables and the option price it will be useful to break the problem into special cases and view the variables in partial isolation. The following examples will be presented in terms of call options.

3.1 Option Prices at Expiration

To illustrate this notion, consider a call option as a function of just S, E, and t with the following example:

$$C = C(\$2.00,\$1.50,.25) = \$.80$$

Here, the call option is on an asset currently selling for \$2 with a strike price of \$1.50 and four months until expiration. The option is selling for \$.80. But what happens when the option is at or near expiration (t=0)? Only two relationships between the asset price and the exercise price can exist either S>E or S≤E. If the asset price is less than or equal to the exercise price the call option has no value and the owner will let it expire worthless.

$$\text{when } S \leq E,\ C(S,E,0) = \$0$$

Alternatively, if the asset price is greater than the exercise price, the value of the option is the difference between the two values:

$$S>E,\ C(S,E,0) = S-E$$

Combining the two scenarios:

$$C(S,E,0) = \max(0,S-E)$$

At expiration, the call option is worth the greater of 0 or S-E.

3.2 Option Prices with Zero Strike and Infinite Expiration Horizon

In an effort to set further boundaries on possible option prices, consider an option with an exercise price of zero and an infinite time horizon until expiration. The option can be exchanged at any time until expiration for the price of the asset. In other words the option can be exchanged at any time for the underlying asset itself. Because of this, the option's value is always equivalent to the value of the underlying asset.

$$C(S,0,\infty) = S$$

Thus the upper bound of the options price is the asset price itself, while as shown earlier, the lower bound is zero. All other options on this asset will fall between these two values.

3.3 Relative Prices of Options that Vary by Strike Price and Time

The next relationships to be discussed concern options on the same asset but with different strike prices and expiration dates. First if:

$$E_1 < E_2,\ C(S,E_1,t) \geq C(S,E_2,t)$$

The two options vary only by the exercise price, the option with the lower exercise price must have a value equal to or greater than the option with the higher exercise price. If both options are in the money (S>E) the one with the lower strike price (E_1)allows a trader the right to purchase the asset at the lower E_1 price. The trader can earn E_2 -E_1 more.

Similarly, when:

$$t_1 > t_2,\ C(S,E,t_1) \geq C(S,E,t_2)$$

The two options are identical except for the time to expiration. The option with the longer time to expiration will be worth more or at least as much as the option with the shorter life. This makes intuitive sense since the option with a longer time to expiration gives the owner more advantages. An out of the money option may change sides as the value of the asset changes with time.

An option with a long remaining life selling for less than an option with a short remaining life would lead to an arbitrage opportunity. A trader could sell the short maturity option and buy the long maturity option, realizing a positive cash flow. If the sold option is exercised by the buyer, the trader can exercise the longer term option and deliver on the sold option. The positive cash-flow will be preserved no matter how the value of the underlying asset changes. We know that an option must be worth at least as much as S-E, however, an in the money option with time left to expiration is often worth more than S-E. The difference between S-E and the cost of the option is known as its intrinsic value, but only part of the intrinsic value is attributable to the time remaining until expiration.

3.4 The Effect of Interest Rates on Option Prices

To further define the price of an option we can look at the effect of interest rates on option values. To illustrate by example, we assume an asset currently sells for \$2 and its price can change value by ±\$.10 over the course of one year. 50 units of this asset will cost \$100 now and may be worth \$105 or \$95 in the future. We also assume that a call option with a strike price of \$2 can be purchased on the asset. The final assumption is that the risk free rate of interest is 6%. We will set up two portfolios. Portfolio 1 contains 50 units of the asset and is worth \$100. Portfolio 2 contains a one year \$100 bond with a present value of \$94.34 and a call option for 50 units of the asset with an exercise price of \$100. In one year, portfolio 1 will be worth either \$95 or \$105. Portfolio 2 contains a bond that will be worth \$100. It also contains an option that will be worth \$5 if the asset price goes up or nothing if the price goes down. Again, portfolio 1 can lead to gains of \$5 or losses of \$5 while portfolio 2 can only lead to profits ranging from 0 to \$5. Clearly, portfolio 2 is the better choice. Since the investor can do just as well or better with portfolio 2, it must be worth more or at least as much as portfolio 1. Since portfolio 1 costs \$100 and the bond in portfolio 2 costs \$94.34, the value of the option must be worth at least \$5.66. The value of the option is greater than or equal to the value of the underlying asset minus the present value of the exercise price.

$$C \geq S\text{-}PV(E)$$

Obviously, the higher the rate of interest, the higher the value of the option. So, if:

$$r_1 > r_2\text{, } C(S,E,t,r_2) \leq C(S,E,t,r_1)$$

3.5 The Effect of Asset Volatility on Option Prices

Now we can address the final variable affecting the price of the option. Consider the previous portfolio 2 where the option could be worth 0 to \$5 at expiration. We now add a third portfolio with an option on 50 units of an asset currently selling for \$2.00 but which may be worth \$2.40 or \$1.60 one year in the future. Like portfolio 2, portfolio 3 also contains a \$100 one year bond. In one year portfolio 3 may be worth \$15 more than portfolio 2 with no additional risk. The fact that the asset underlying the option in portfolio 3 exhibits more risk actually adds to the value of its option (holding all else constant). Portfolio 3 must be worth more than portfolio 2 because of the higher range of possible profits.

$$\sigma_1 > \sigma_2\text{, } C(S,E,t,r,\sigma_1) \geq C(S,E,t,r,\sigma_2)$$

At first glance, portfolio 2 displays an apparent problem. You pay \$5.66 for an option that will be worth somewhere between 0 and \$5 in one year. This seems to be a poor investment. However, you will note that holding portfolio 2 ensures that the value of the portfolio will not be worth less than \$100 at option expiration. In a sense, you are insuring against the -\$5 possibility of portfolio 1. Thus, the higher the risk of the underlying asset, the higher the price of the insurance. This is denoted as;

$$C(S,E,t,r,\sigma) = S\text{-}PV(E) + I$$

Up to this point we have been able to put boundaries on possible option prices, but we have not been able to pin down the actual prices. We know that call option values increase for higher levels of interest, longer lengths of time, higher asset prices, higher strike prices, and higher asset price volatility. However, for any particular mix of these five variables, we have not shown any way to find an exact option price.

4 Black-Scholes Option pricing Model

The first model to directly calculate options prices was developed by Fischer Black and Myron Scholes in their seminal work, "The Pricing of Options and Corporate Liabilities." Their model (B-S) values **European** options on non-dividend paying stocks. Unlike American options, European options can only be exercised at option expiration. Although we are ultimately looking for values (standard deviations) associated with American futures options, it is essential that we analyze the construction of the B-S model before we can analyze the special case of American options.

One of the central assumptions of the B-S model is that the price movements of the underlying asset follow a stochastic 'wiener' process where asset prices change continuously through time and changes made over any given time period are distributed normally. B-S also makes the following simplifying assumptions: (1) there are no taxes or transaction costs; (2) the underlying asset exhibits no dividends or other leakage and its returns are lognormally distributed with constant variance; (3) markets operate continuously; (4) interest rates are constant and risk free. Black and Scholes derived their valuation model by forming a riskless hedged portfolio consisting of a long position in the underlying asset and a short position in the asset's call option. The payoff to the hedged portfolio is the riskless rate of interest (in equilibrium) and represents a non-stochastic partial differential equation for the value of the asset call option. The partial differential is expressed as:

(1) $$\delta C^e/\delta t = rC^e - .5(\sigma^2 S^2 \delta^2 C^e/\delta S^2)$$
C^e = European call option value

and can be solved subject to the following boundary conditions:

(2) $C^e(S,E,t) = MAX\ [0,S-E]$ where $t=0$
(3) $C^e(S,E,t) = 0$ where $S=0$

Formally the Black-Scholes model for a call option is as follows:

$$C^e\ (S,E,r,t,\sigma) = SN(d_1) - Ee^{-rt}N(d_2)$$

where
$$d_1 = [\ln(S/E)+(r+.5\sigma^2)t]/\sigma\sqrt{t}$$
$$d_2 = d_1 - \sigma\sqrt{t}$$

$N(d_1)$ and $N(d_2)$ = cumulative normal probabilistic values of d_1 and d_2. The use of the normal probability function gives the B-S model its ability to incorporate the price risk of the asset into the option price.

Using the values from the previous intuitive example where:

$S = \$2.00$ $E = \$2.00$
$t = 1$ year $r = 6\%$
$\sigma = 5\%$

The price of the option can be calculated using the B-S model:

$d_1 = [\ln(2/2) + (.06+.5(.05)2)1]/.05$
$= 1.225$

$d_2 = 1.225 - .05$
$= 1.175$

d_1 and d_2 are simple z scores that can be looked up in a table:
$N(1.225) = .8897$
$N(1.175) = .88$

Therefore $C = 2(.8897) - 2e^{-(.06)}(.88) = \$.122$
This value, when multiplied by 50 becomes \$6.10. This is quite close to the \$5.66 value derived from our portfolios 1 and 2.

Note that the term Ee^{-rt} is the present value of the exercise price with continuous discounting. The B-S model essentially becomes:

$$C = SN(d_1) - PV(E)N(d_2)$$

Taking this one step further, if the stock had no risk, N(d1) and N(d2) would both equal one. The B-S equation then, would further be simplified to $C = S - PV(E)$, the exact equation we found through intuition (section 3.1.4).

5 Pricing Options on Futures - Black Model

Like asset options, options on futures contracts give the owner the right to exercise the option and give the seller the obligation to perform on the contract. As noted earlier, the B-S model was developed to price European options on non-dividend stocks. American options on assets without dividends have the same price as the equivalent European option but options on futures contracts do not fall into this category. Because these contracts are settled on a daily basis, the cash flows associated with settlement act as a continuous dividend. Thus, futures contracts violate one of the B-S assumptions.

In order to help solve the problem, Black (1976) adjusted the B-S model to value call options on futures contracts:

$$C(F,E,t,r,\sigma) = e^{-rt}[FN(d_1*)-EN(d_2*)]$$

where t = time to expiration of the forward contract
r = risk free rate of interest
F = current futures price for contract expiring at t
E = strike price
σ = annualized standard deviation of the futures contract price

$$d_1* = [\ln(F/E)+.5\sigma^2 t]/\sigma\sqrt{t}$$
$$d_2* = d_1* - \sigma\sqrt{t}$$

Notice that in the Black model the r term drops out of the calculation of d_1. Also, the entire pricing equation is discounted by e^{-rt}. Therefore under the certainty assumption, the option is worth the present value of the proceeds:

$$C = e^{-rt}[F-E]$$

Early exercise is possible and often desirable when dealing with American options on futures contracts. American options can be viewed as a continuous series of European options. When the option is exercised you receive the explicit value from that option (F-E), but give up the right to any future gains above F-E. Consider the case of a call option with a strike price of $1.50 on a futures contract currently selling for $2. Here the trader could exercise the option and collect $.50. This $.50 can then earn interest through the original option expiration date. The interest accrued is equal to $e^{rt}(F-E)-(F-E)$. These calculations only hold when the futures price does not change over the remaining life of the contract - an unlikely scenario. Instead there is a chance that the futures price may move up and the trader will lose additional profits. This tradeoff between exercising early and foregoing potential additional gains is what makes American options difficult to model.

Values of N(d1*) and N(d2*) approach one when the futures price becomes very large relative to the exercise price{ $C = e^{-rt}[F_{0,t}-E]$}. As shown above, the minimum value for a European futures option is $e^{-rt}[F-E]$. This happens when it is almost certain that the option will remain in the money and pay F-E at expiration. Basically, at high futures prices the European option value converges to the present value of the exercisable proceeds. It will not exceed this value because the proceeds are not available until the expiration date.

6 Model for Pricing American Options on NYMEX Natural Gas Futures

Unlike the Black Scholes model for European options, no closed form, analytic model exists for pricing American options. The early exercise potential of American options generally places the value of these options above that of their European counterparts. It is the peculiar nature of this early exercise 'premium' that makes the American option difficult to model.

Because American options can be exercised early, they are always worth at least as much as a comparable European option. Each American option has a critical value (F*)or maximum futures price which is defined as the minimum futures value where the option's price equals F-E. When the futures price equals this critical value, the call owner is indifferent between holding and exercising the option. If the futures price is greater than F*, the trader should exercise the option immediately and earn the interest on the proceeds. If the futures price is less than F* the trader should hold or sell the option. F* represents the point at which the costs and the benefits of holding the option are equal. When the futures price is below F* the B-S model cannot accurately value the American option. Its price is equal to the European option value plus an early exercise premium.

The value of American call options, however, can be approximated by solving:

(4) $$C^a(F,E,r,\sigma,t^*) = MAX[C^a(F,E,t^*), F-E]$$

C^a = value of an American call option

where $C^a(F,E,t^*)$ is the value of an unexercised option at time t*, an instant of time after t. This represents the boundary condition for the early exercise premium of the American call option. For each time $t<t^*$ there is a critical futures price, F* above which early exercise of the option is optimal.

Barone-Adesi and Whaley Model (BA-W)

The Barone-Adesi and Whaley (1987) model is one of the most widely used of several analytical approximations for American option values. Building on the standard Black model for European futures options where:

(5) $$C^e = e^{-rt} [FN(d)-EN(d-\sigma\sqrt{t})]$$

and where $$d = [ln(F/E) + .5\sigma^2 t]/\sigma\sqrt{t}$$

Barone-Adesi and Whaley add constraint (4) and express the American option value as:

(6) $$C^a(F,E,t,r,\sigma) = C^e + A_2(F/F^*)^{q_2}$$ where $F<F^*$, and

(7) $$C^a(F,E,t,r,\sigma) = F-E$$ where $F\geq F^*$,

C^a = American call value

C^e = European call value

and where $A_2 = (F^*/q_2)\{1-e^{-rt}N[d_2(F^*)]\}$
$d_2(F^*) = \{ln(F^*/E)+(\sigma^2/2)t\}/ \sigma\sqrt{t}$
$q_2 = (1+\sqrt{(1+4K)})/2$
$K = 2r/[\sigma^2(1-e^{-rt})]$
$N(\cdot)$ = is the cumulative univariate normal distribution

and F* equals the critical gas futures price above which the natural gas futures call option should be exercised immediately. Equation (6) explains that if the gas futures price falls below F*, then the American call value equals the corresponding European call value plus an early exercise premium of $A_2(F/F^*)^{q_2}$. For futures equal to or above F*, C^a should be exercised at its F-E value.

F* is determined iteratively by solving:

(8) $$0 = F^*-E - C^e(F^*,E,t,r,\sigma) - \{1-e^{-rT} N[d_2(F^*)]\}F^*/q_2$$

The value of F* can then be inserted into equation 6 to solve for the value of the American call option.

The value of American put options is derived in very much the same way. The B-AW equations for put options are:

(9) $P^a(F,E,t,r,\sigma) = P^e + A_1 (F/F^*)^{q_1}$ where $F>F^*$ and
(10) $P^a(F,E,t,r,\sigma) = E-F$ where $F \leq F^*$,

where $A_1 = (F^*/q1)\{1-e^{-rt} N[-d_2(F^*)]\}$
$q_1 = (1- \sqrt{(1+4K)})/2$

here, P^e, the Black and Scholes European value of the put option is expressed as:

(11) $$P^e = e^{-rT} EN(-d + \sigma \sqrt{T})-e^{-rt} FN(-d)$$

The F* of the put option is the critical futures price below which the American natural gas futures option should be exercised immediately. Like the call option, it is calculated iteratively by solving:

(12) $$0 = E-F^* - P^e(F^*,E,t,r,\sigma) +\{1-e^{-rt} N[-d_2(F^*)]\} F^*/q_1$$

We are not really interested in solving for the prices of options. In fact, we already know their values through observations of trades on the commodities exchanges. We are interested in the values of the standard deviations used to price the options. Since the standard deviation is an integral part of the pricing of options, it makes sense that this value can be backed out of the model. We have five observed values (C^a,F,E,T,r), two equations, and two unknowns (σ,F*). To solve for the standard deviation of a call option, simultaneously solve equations 6 and 8 setting equation 6 equal to the observed option value.

7 Weighted Implied Standard Deviation of Futures Contracts

The standard deviation derived from the option pricing formula is often referred to as the implied standard deviation (ISD). It is not uncommon for various options on a particular gas contract to produce different implied standard deviation values on any given day. While troubling, this does not necessarily mean that the option model is incorrect. Multiple values of the standard deviation for the same futures contract may exist because of the way option prices are reported. Most option prices are reported at the close of the business day and are associated with the closing price of the futures contract. The option may have actually been sold while the futures price was at a higher or lower value at some other point in the day. Additional reasons may include over or under valued option prices (inefficient market) or a mispecified model.

If the assumptions of the Black model (and B-AW for that matter) hold true and all information enters options markets efficiently, all options on an asset will be priced from the same standard deviation. As noted this is often not the case. Some options appear to rely more heavily on precise measures of the standard deviation than others (even in highly efficient markets). For example, a call option with very little time to expiration, where the strike price is well below the futures price is not very sensitive to changes in the underlying standard deviations (Latane and Rendleman,1976). Because of this, it is not unreasonable to arrive at the conclusion that options displaying high sensitivity to changes in the standard deviation will be better estimators of the actual value of σ. An option trader will devote more time to estimating the standard deviation if the option price is highly sensitive to it's value.

Simply averaging the standard deviations derived from a set of option prices may hide the market's actual assessment of the true standard deviation. Options displaying high sensitivity to changes in the standard deviation should be given more weight than options displaying low sensitivity. Chiras and Manaster developed a method of combining these various ISD's into a single weighted average implied standard deviation (WISD). They note that rational investors measure returns as the ratio of dollar price change to the size of the overall investment. To be consistent with this rationale, the price elasticity of each option with respect to its implied volatility is considered when constructing the WISD from a set of option ISDs. The elasticity is a measure of the percent change in the option value with respect to the percent change in the ISD. From these individual elasticities and ISD's, Chiras and Manaster construct a constant weighted ISD for the future value of the assets.

The key to calculating the WISD is finding the correct value of VEGA (V). Vega is a common option pricing term describing the change in option value for a small unit change in volatility (σ).

(13) $$V_j = \delta W_j/\delta\sigma_j \approx F\,\sqrt{(t)}\,\{(1/\sqrt{(2\pi)})\,e^{(-((d1_j)^{\wedge}2)/2)}\}$$

where W is the price of the option, t is the time to expiration and F is the current futures price. The WISD is determined by:

(14) $$\text{WISD} = \sum_{j=1}^{N} \sigma_j\{[V_j(\sigma_j/W_j)]/[\sum_{j=1}^{N} V_j(\sigma_j/W_j)]\}$$

where

N = the number of options recorded for a particular asset on a particular date,
σ_j = the implied standard deviation for option j of the asset.

8 The Mean and the Variance of the Distribution of Natural Gas Futures

The mean of the distribution

The BA-W model is based on the assumptions that the gas futures market is informationally efficient and that futures prices follow a random walk. The expected value of a futures contract T periods from now is its current value (Samuelson - 1965). Following Overdahl and Matthews (1987) this implies that the mean of the lognormal distribution of the futures price tomorrow is estimated by the current futures price. The mean of the distribution of logarithmic futures prices can be expressed as :

(15) $$E[ln(F)] = ln[E(F)] - VAR/2$$

Here, all expectations are made for time t+T at time t (where T is the expiration date and t is the observation date). F represents the futures price at time t of a contract ending at t+T and VAR is the variance of the distribution of logarithmic futures prices. Note that the mean of the distribution of lognormal futures prices is not the same as the logarithm of the mean of the distribution of futures prices. Additionally, Overdahl and Matthews assert that any risk premium embedded in the futures price is minimal. It is assumed that this assertion holds for the Gas futures market as well.

The variance of the distribution

Again following Overdahl and Matthews, the assumption that futures prices are distributed lognormally is equivalent to assuming that logarithmic futures prices are distributed normally. Given this assumption, the standard deviation of logarithmic futures prices can be approximated by the B-AW model. The following equations relate the price relatives of the B-AW model to equation 15:

(16) $$ln(F_{t+T}/F_t) = \mu T + \sigma\sqrt{T}Z$$

where (F_{t+T}/F_t)-future price relative over instant t to t+T
μ - mean of logarithmic futures price per unit of time
σ - the standard deviation of the futures price relative per unit of time
Z - standard normal random variable with a mean of zero and σ of one

Equation 16 can be re-written in the form of equation 15:

(17) $ln(F_{t+T}) = [ln(F_t) + \mu T] + \sigma\sqrt{T}Z$

thus the standard deviation of the distribution of logarithmic futures prices at time t+T is $\sigma\sqrt{T}$. Note that this equation has the effect of converting the futures price and the annualized standard deviation observed at time t to a forecast for time t+T.

By definition, efficient markets reflect all available information, the variances calculated from option prices should reflect the information content of historical futures prices and all other information available at the time. The equations above show how to derive the market's assessment of the mean and variance of the distribution from which futures prices are drawn. Given these values and assuming a lognormal form for the distribution of futures prices, the mean and variance of the distribution from which futures prices will be drawn can be approximated. Future logarithmic futures prices will be distributed normally with a mean $ln(F)-\sigma^2T/2$ and a standard deviation of $\sigma\sqrt{T}$.

9 Calculating the Mean and Variance of the Distribution

As previously noted, the forecast of natural gas futures prices is based on five variables. Four of the variables are directly observable through the market while one variable (the standard deviation) is calculated through the use of equations 6 and 9. To demonstrate the forecast method, NYMEX price data for the October futures and options contracts - closing August 29, 1997 - were collected. The 90 day bond yield reported on this date was used to reflect the short-term riskless rate of return.[1] For reliability reasons, prices for any option with a volume less than five were deleted. Table 1 lists the remaining data (for informational purposes, the volumes are included in the table as well).

On August 29 the closing futures price for Henry Hub natural gas was $2.714 per MMBtu. 17 calls and eight puts were actively traded with prices ranging from $.72 to $.012 per contract. Strike prices ranged from $2.00 to $3.20 for calls and $2.70 to $2.05 for puts. The 13 week bond equivalent yield was 5.24%. Since the options expired on September 25, 1997, .0742 years remained until option expiration. These inputs are used to produce the individual standard deviations for each option. The Vega for each option is then calculated by reinserting the five variables into equation 13. The standard deviations and the Vegas' are listed in Table 1.

Continuing with the model, the Vega and standard deviation values are combined to form the 'weighted' standard deviation. Calculations of portions of equation 13 are listed in Table 2:

$$WISD = \sum_{j=1}^{25} \sigma_j\{[V_j(\sigma_j/W_j)]/[\sum_{j=1}^{25} V_j(\sigma_j/W_j)]\}$$

[1] Daily data for natural gas futures contracts and options on gas futures contracts were obtained from the New York Mercantile Exchange. Short term interest rates (90 day bond equivalent yields) were obtained on-line from the Federal Reserve H.15 database. August 29, 1997 was chosen because of the large number of contracts traded on that day.

Table 1: Implied Standard Deviations and Vega's

NYMEX closing data from August 29, 1997
Contract price being forecasted: Oct. 97 Natural Gas
Futures contract value: $2.714
Option expiration date: Sept. 25, 1997
Time to expiration: .0742years
Short term interest rate (bond yield): .0524
Weighted Implied Standard Deviation: .592 (.161 over t+T)

Put/Call	Volume	Strike Price	Option Value	Implied Std. Dev.	Vega
C	11	$2.00	0.723	0.300	0.000
C	10	$2.20	0.531	0.597	0.107
C	5	$2.25	0.486	0.586	0.130
C	6	$2.35	0.401	0.574	0.180
C	7	$2.40	0.362	0.573	0.205
C	5	$2.50	0.287	0.559	0.250
C	42	$2.60	0.226	0.567	0.281
C	8	$2.65	0.199	0.569	0.284
C	306	$2.70	0.174	0.569	0.292
C	191	$2.75	0.148	0.558	0.295
C	2438	$2.80	0.129	0.563	0.292
C	131	$2.85	0.111	0.565	0.283
C	158	$2.90	0.096	0.570	0.269
C	197	$3.00	0.073	0.585	0.253
C	40	$3.05	0.064	0.595	0.231
C	27	$3.10	0.055	0.598	0.233
C	2027	$3.20	0.039	0.599	0.183
P	5	$2.05	0.012	0.678	0.085
P	35	$2.20	0.019	0.604	0.108
P	302	$2.30	0.029	0.574	0.155
P	201	$2.35	0.038	0.574	0.180
P	12	$2.40	0.049	0.574	0.205
P	27	$2.50	0.074	0.561	0.250
P	145	$2.65	0.135	0.568	0.284
P	485	$2.70	0.16	0.569	0.292

Table 2: Weighted Implied Standard Deviations

Put/ Call	j	Strike Price	σ_j	$V_j(\sigma_j/W_j)$	$\Sigma V(\sigma/W)$	$\sigma j \bullet [V_j(\sigma_j/W_j)/ \Sigma V(\sigma/W)]$	Annualized WISD
C	1	2.00	0.300	0.000	39.331	0.000	0.592
C	2	2.20	0.597	0.121	39.331	0.002	0.592
C	3	2.25	0.586	0.157	39.331	0.002	0.592
C	4	2.35	0.574	0.257	39.331	0.004	0.592
C	5	2.40	0.573	0.324	39.331	0.005	0.592
C	6	2.50	0.559	0.487	39.331	0.007	0.592
C	7	2.60	0.567	0.705	39.331	0.010	0.592
C	8	2.65	0.569	0.811	39.331	0.012	0.592
C	9	2.70	0.569	0.956	39.331	0.014	0.592
C	10	2.75	0.558	1.112	39.331	0.016	0.592
C	11	2.80	0.563	1.274	39.331	0.018	0.592
C	12	2.85	0.565	1.440	39.331	0.021	0.592
C	13	2.90	0.570	1.600	39.331	0.023	0.592
C	14	3.00	0.585	2.025	39.331	0.030	0.592
C	15	3.05	0.595	2.147	39.331	0.032	0.592
C	16	3.10	0.598	2.532	39.331	0.039	0.592
C	17	3.20	0.599	2.806	39.331	0.043	0.592
P	18	2.05	0.678	4.823	39.331	0.083	0.592
P	19	2.20	0.604	3.437	39.331	0.053	0.592
P	20	2.30	0.574	3.069	39.331	0.045	0.592
P	21	2.35	0.574	2.718	39.331	0.040	0.592
P	22	2.40	0.574	2.400	39.331	0.035	0.592
P	23	2.50	0.561	1.894	39.331	0.027	0.592
P	24	2.65	0.568	1.195	39.331	0.017	0.592
P	25	2.70	0.569	1.039	39.331	0.015	0.592

The standard deviation of future logarithmic October futures prices implied by the options is:

$$(\text{WISD}) \bullet \sqrt{T} = .592\sqrt{(.0742)} = .161$$

with a mean of:

$$ln(F)-\sigma^2T/2 = ln(2.714) - .026/2 = .985$$

10 Testing the WISD

If the option market is truly efficient the prices will reflect all available information. Additionally, the variances derived from the pricing model should reflect all information contained in the history of the futures price as well as any additional information that may have been available at the time of the trade. Thus the WISD values obtained from options prices may reflect future values of the standard deviation better than historical observations alone.

The following test is designed to determine some of the predictive characteristics of the information contained in the natural gas futures options prices. The test follows the methodology used by Chiras and Manaster to determine the predictive ability of stock option prices. The hypothesis behind the test is that standard deviations inferred by options prices have been better predictors of future standard deviations than standard deviations obtained from historic futures prices.

The test involves the creation of three monthly series of annualized volatility measures covering natural gas data from1993-1996. Like the previous WISD example, all of the options and futures data used in this test were obtained directly from the NYMEX. The yield data was obtained from the Federal Reserve. At the beginning of each month (or as close to the beginning as possible), a historical (SDHIST), weighted option implied standard deviation (WISD), and a future (SDFUT) standard deviation are created.

With the beginning of the month designated day t, the annualized historical standard deviation is measured with futures price movements from t-14 up to and including t (15 observations). To annualize the data, the log of each daily price change is calculated (ln[t-14/t-13]). This new series is then averaged and differenced from the mean. The sum of these differences is then divided by the number of elements (in this case fourteen) and multiplied by the number of trading days in a year. The square root of this final number is the annualized standard deviation. The future standard deviation is calculated in a similar fashion except the price movements are measured from time t+1 until the expiration of the futures contract. This may be anywhere from 12 to 17 observations.

Finally, the WISD is calculated from closing options prices and the closing futures price on day t. Like the previous WISD example, any option with a volume less than five is discarded. Because of the low volume, the prices of these options may not be good indicators of market conditions. In addition, any option, put or call, with a strike price more than 25% away from the observed futures price is removed.

Forty nine observations for each element (SDFUT, SDHIST, and WISD) were calculated using the data set. The 49th observation was calculated since the set actually begins with November 1992 options data on the December 1992 futures contract.

Using regression analysis, the SDHIST's and WISD's are then compared to the SDFUT's to determine which predictor is superior over the time period. The following two regression equations are used to test the hypothesis:

(18) $SDFUT = a_h + B_h SDHIST + e_h$

(19) $SDFUT = a_o + B_o WISD + e_o$

a_x and B_x are the coefficients on the constants and independent variables respectively e_x represents the error of each regression. Table 3 displays the regression output from equation 18 and table 4 displays the output from equation 19.

Both regressions indicate that the SDHIST's and WISD's may be significant. Their high t-ratios indicate that we can reject the null hypothesis that the B coefficient is zero for each regression. The most useful information that can be obtained from the regressions is the adjusted R-squared values. The R-squared value for equation 18 is .507, indicating that historic standard deviations (and the constant) explain 51% of the future standard deviations of futures price movements. On the other hand, the R-squared for equation 19 is .60. This implies that the option implied standard deviation can explain 60% of the future standard deviations. Also note that the constant in the regression of equation 19 is not significant. This indicates that the R-squared does not significantly improve with the inclusion of a constant.

The differences between the two equations are not dramatic. However, based on the evidence provided by the two R-squared values, the WISD based equation represents roughly a 20% improvement in predictive power over the SDHIST's. Based on this evidence we can conclude that the WISD based predictions are better indicators of future standard deviations of futures price movements.

Table 3: SDHIST Regression

$SDFUT = a_h + B_h SDHIST + e_h$

Ordinary least squares regression.		Dep. Variable =	SDFUT
Observations =	49	Weights =	ONE
Mean of LHS =	0.4160176E+00	Std.Dev of LHS =	0.1958048E+00
StdDev of residuals=	0.1374370E+00	Sum of squares =	0.8877802E+00
R-squared =	0.5175886E+00	Adjusted R-squared=	0.5073246E+00
F[1, 47] =	0.5042723E+02	Prob value	0.5108854E-08
Log-likelihood =	0.2873787E+02	Restr.(á=0) Log-l =	0.1087840E+02
Amemiya Pr. Criter.=	0.1965992E-01	Akaike Info.Crit. =	-0.1091342E+01

ANOVA Source	Variation	Degrees of Freedom	Mean Square
Regression	0.9525169E+00	1.	0.9525169E+00
Residual	0.8877802E+00	47.	0.1888894E-01
Total	0.1840297E+01	48.	0.3833952E-01

Durbin-Watson stat.= 1.9803598 Autocorrelation = 0.0098201

Variable	Coefficient	Std. Error	t-ratio	Prob|t|òx	Mean of X	Std.Dev.of X
Constant	0.13159	0.4461E-01	2.950	0.00494		
SDHIST	0.74812	0.1054	7.101	0.00000	0.38019	0.18830

Table 4: WISD Regression

$SDFUT = a_c + B_c WISD + e_c$

```
Ordinary    least squares regression.     Dep. Variable       =  SDFUT
Observations          =            49     Weights             =  ONE
Mean of LHS           =  0.4160176E+00    Std.Dev of LHS      =  0.1958048E+00
StdDev of residuals=     0.1237619E+00    Sum of squares      =  0.7198996E+00
R-squared             =  0.6088134E+00    Adjusted R-squared=    0.6004903E+00
F[  1,     47]        =  0.7314726E+02    Prob value             0.0000000E+00
Log-likelihood        =  0.3387338E+02    Restr.(á=0) Log-l  =   0.1087840E+02
Amemiya Pr. Criter.=     0.1594220E-01    Akaike Info.Crit.  = -0.1300954E+01
ANOVA  Source            Variation      Degrees of Freedom       Mean Square
       Regression        0.1120398E+01          1.                0.1120398E+01
       Residual          0.7198996E+00         47.                0.1531701E-01
       Total             0.1840297E+01         48.                0.3833952E-01
Durbin-Watson stat.=     1.7426882        Autocorrelation    =   0.1286559
Variable  Coefficient    Std. Error    t-ratio Prob|t|òx   Mean of X  Std.Dev.of X
-----------------------------------------------------------------------------------
Constant -0.10053E-01    0.5286E-01    -0.190  0.84999
WISD       0.98100       0.1147         8.553  0.00000   0.43432       0.15574
```

11 Constructing the Options Based Forecast

Arbitrarily constructing a price interval around the observed futures price (say ±25%), one can calculate the probability that the futures price will fall within the constructed range at option expiration. Following the example from section 9 , the ±25% interval around the October futures price becomes \$2.036 to \$3.39 MMBtu. The probability is expressed as:

(20) $$\text{Prob}\ (2.036 < F < 3.39)$$

Since the mean and standard deviation produced by the model are expressed as logs equation (20) should be expressed as:

(21) $$\text{Prob}\ (ln(2.036) < ln(\text{futures}) < ln(3.39))$$

Expressing (21) in standardized normal form:

$$\text{Prob}\ [(.71-.985)/.16 \le (\ln(\text{futures})-.985)/.16 \le (1.22-.985)/.16]$$

or

$$\text{Prob}(-1.7 \le z \le 1.47)$$

Checking a normal distribution table, the cumulative probability that the final futures price will be less than \$2.036 is .044 while the probability gas prices will be below \$3.39 is .929, thus the probability that October spot gas prices will fall between \$2.036 and \$3.39 is 88%.

12 Predictive Ability of the Options Based Forecast

Although the options based forecast model is most useful when the forecasted mean is combined with the qualitative information of the implied standard deviation, it is also useful to know how accurate the model is at predicting the exact level of a futures price at the expiration of the contract. To test the model's predictive ability, a series of monthly forecasts of the mean were constructed using the WISD methodology and equation 15 (e raised to the calculated mean of 17). The monthly forecasts were then compared to the actual values of the gas prices on the dates being forecast. The predicted and actual prices for each forecast date are listed in Appendix Table 1a. Each forecast was derived from mid-month options prices. Again, all options with less than five trades on the forecast date were discarded and any option with a strike price of more than ±25% of the underlying futures price was also removed from the test. For comparison purposes, predictions based on a 15-day and 30-day moving averages of the futures price were also calculated.[2] The sum of squared errors, mean square error, and root mean square error for each of the three forecasting methods are listed in Table 5.

Options estimate	
sse	3.2838229
mse	0.0781863
rmse	0.2796181

15-day avg. estimate		**30-day avg. estimate**	
sse	4.5575136	sse	5.9057323
mse	0.1085122	mse	0.1406127
rmse	0.3294119	rmse	0.3749836

Table 6: Forecast Extremes

	Option Error	15-day error	30-day error
Max. underestimate:	$1.088	$1.272	$1.386
Max. overestimate:	($0.549)	($0.432)	($0.508)
Standard Deviation:	$0.28058	$0.3291	$0.37308

[2] The options and futures data used in this test were obtained from the NYMEX.

Over 42 observations, the standard deviation of the error produced by the options estimates was .28 with a maximum underestimate of $1.088 and a maximum overestimate of $.55. This compares to a standard error of .33 for the 15-day average and .37 for the 30-day average. The evidence indicates that the options based forecast is superior to either of the moving average based prediction methods.

13 Conclusions

This paper demonstrated that information about the future distribution of natural gas prices can be obtained from the prices of options on gas futures contracts. The theory behind option pricing was outlined. A model for valuing American options on futures contracts was presented and linked to the theory. Finally a method for using the pricing model to derive and weight the implied standard deviations contained in option prices was discussed. Since the model depends on futures and options prices, it theoretically contains all the information utilized by the open market in pricing the futures and options prices themselves. If these markets are in fact informationally efficient, the mean and standard deviation produced by this model should be an assessment of the market's 'consensus' opinion of their future values.

Regressions run on the weighted implied standard deviations indicated that they may be better estimators of the future standard deviations than ordinary standard deviations based on historical information. Additionally, the ability of the futures/options derived mean to predict the expiration price of the futures contract was explored. The futures/options based forecast compared favorably to the 15-day and 30-day rolling average estimates.

Market analysts can use the methods outlined here to benefit from expert opinion and expensive information often associated with market professionals and complex models without actually hiring consultants or paying for expensive market forecasts. With this in mind, analysts can use this model to develop new forecasts based entirely on NYMEX data and model output. They could also assess the probability of prices developed using old forecasting methods or independently verify and critique external forecasts (such as those purchased from financial service consultants).

The method of deriving market based forecasts outlined in this paper is easy to implement and quite flexible. Many computer programs exist (often as add-ins to popular spreadsheet software titles) that will solve for the implied standard deviation of an option given the current option price, futures price, risk-free interest rate and time until expiration. The user will not have to bother with the onerous task of coding the solution to the B-AW model. In addition, several financial services companies now supply real-time trading data via computer. Generally, this data can be linked directly to a spreadsheet allowing the user to track changes in market prices and conditions. This real-time data coupled with a spreadsheet option valuation model could allow any user to monitor instantaneous changes in the probabilities surrounding several months of futures forecasts.

The NYMEX currently lists options on contracts with maturities of up to three years, however, the practical range of the model is limited by the low volume of trades that actually take place on the long-range options. An observation of volumes indicates that the practical limit on forecasts is about four months. The market for natural gas futures contracts has, however, been growing quickly over the past few years. This rapid growth may carry-over into the market for options on these contracts. As the market for longer term options increases, the reliability of long range option based forecasts will also improve.

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Appendix

Table 1a: Forecast Data

Forecast Date	Target Date	Options estimate	15-day futures estimate	30-day futures estimate	Actual futures price
3/15/93	3/24/93	$1.96	$1.86	$1.79	$2.22
4/15/93	4/23/93	$2.35	$2.15	$2.06	$2.76
5/14/93	5/21/93	$2.26	$2.26	$2.31	$2.12
6/15/93	6/23/93	$2.15	$2.13	$2.17	$1.92
7/15/93	7/23/93	$2.03	$2.13	$2.13	$2.12
9/15/93	9/23/93	$2.12	$2.31	$2.31	$2.27
10/15/93	10/22/93	$2.17	$2.21	$2.21	$2.16
12/15/93	12/22/93	$2.01	$2.10	$2.23	$2.02
1/14/94	1/24/94	$2.27	$2.10	$2.07	$2.47
3/15/94	3/24/94	$2.10	$2.17	$2.28	$1.98
4/15/94	4/22/94	$2.19	$2.10	$2.10	$2.08
6/15/94	6/23/94	$2.17	$2.00	$1.98	$1.97
7/15/94	7/22/94	$1.95	$2.09	$2.08	$1.79
8/15/94	8/24/94	$1.75	$1.78	$1.88	$1.48
9/15/94	9/23/94	$1.62	$1.63	$1.66	$1.41
10/14/94	10/24/94	$1.63	$1.67	$1.63	$1.68
11/15/94	11/21/94	$1.73	$1.85	$1.75	$1.66
12/15/94	12/22/94	$1.71	$1.77	$1.76	$1.64
1/16/95	1/23/95	$1.38	$1.54	$1.63	$1.39
2/15/95	2/21/95	$1.38	$1.42	$1.42	$1.43
3/15/95	3/24/95	$1.50	$1.46	$1.45	$1.57
4/17/95	4/21/95	$1.65	$1.65	$1.58	$1.67
5/15/95	5/23/95	$1.73	$1.67	$1.66	$1.76
6/15/95	6/23/95	$1.67	$1.71	$1.71	$1.53
7/14/95	7/24/95	$1.51	$1.53	$1.60	$1.39
8/15/95	8/24/95	$1.55	$1.50	$1.49	$1.58
9/15/95	9/22/95	$1.66	$1.68	$1.61	$1.64
10/16/95	10/24/95	$1.71	$1.78	$1.72	$1.77
11/15/95	11/21/95	$1.92	$1.86	$1.81	$2.24
12/15/95	12/21/95	$2.36	$2.18	$2.06	$3.45
1/15/96	1/25/96	$1.99	$2.70	$2.52	$2.34
2/15/96	2/23/96	$2.55	$2.47	$2.46	$2.75
3/15/96	3/25/96	$2.32	$2.22	$2.36	$2.78
4/15/96	4/24/96	$2.33	$2.36	$2.35	$2.21
5/15/96	5/24/96	$2.29	$2.22	$2.28	$2.36
6/14/96	6/24/96	$2.51	$2.41	$2.33	$2.65
7/15/96	7/25/96	$2.76	$2.75	$2.61	$2.32
8/15/96	8/26/96	$2.03	$2.13	$2.36	$1.85
9/16/96	9/24/96	$1.97	$1.85	$1.96	$1.83
10/15/96	10/25/96	$2.45	$2.30	$2.09	$2.65
11/15/96	11/25/96	$2.90	$2.72	$2.59	$3.49
12/20/96	12/24/96	$4.55	$3.77	$3.45	$4.00

NYMEX Division Specifications[3]

Henry Hub Natural Gas Futures and Options Contract Specifications

Trading Unit
Futures: 10,000 million British thermal units (MMBtu).
Options: One NYMEX Division natural gas futures contract.

Trading Hours
Futures and Options: 10:00 A.M. - 3:10 P.M., for the open outcry session. After-hours trading is conducted via the NYMEX ACCESS® electronic trading system from 4 P.M. to 7 P.M., Monday through Thursday. All times are New York time.

Trading Months
Futures: 36 consecutive months commencing with the next calendar month (for example, on October 3, 1997, trading occurs in all months from November 1997 through October 2000). Options: 12 consecutive months, plus 15, 18, 21, 24, 27, 30, 33, and 36 months on a June-December cycle.

Price Quotation
Futures and Options: Dollars and cents per MMBtu, for example, $2.035 per MMBtu.

Minimum Price Fluctuation
Futures and Options: $0.001 (0.1 ¢) per MMBtu ($10 per contract).

Maximum Daily Price Fluctuation
Futures: $1.50 per MMBtu ($15,000 per contract) for the first two months. Initial back month limits of $0.15 per MMBtu rise to $0.30 per MMBtu if the previous day's settlement price in any back month is at the $0.15 limit. In the event of a $0.75 per MMBtu move in either if the first two contract months, back month limits are expanded to $0.75 per MMBtu in all months from the limit in place in the direction of the move. Options: No price limits.

Last Trading Day
Futures: Trading terminates three business days prior to the first calendar day of the delivery month. Options: Trading terminates at the close of business on the business day immediately preceding the expiration of the underlying futures contract.

Exercise of Options
By a clearing member to the Exchange clearinghouse not later than 5:30 P.M. or 45 minutes after the underlying futures settlement price is posted, whichever is later, on any day up to and including the options expiration.

[3] These specifications were obtained from the NYMEX at http://www.nymex.com/contract/natgas.html

Option Strike Prices
Increments of $0.05 (five cents) per MMBtu with 20 strike prices above and below the at-the-money strike prices, and the next ten strike prices are in increments of $0.25 (25 cents) per MMBtu above the highest and below the lowest existing strike prices for a total of 61 strike prices. The at-the-money strike price is the nearest to the previous day's close of the underlying futures contract. Strike price boundaries are adjusted according to the futures price movements.

Delivery
Sabine Pipe Line Co.'s Henry Hub in Louisiana. Seller is responsible for the movement of the gas through the Hub; the buyer, from the Hub. The Hub fee will be paid by seller.

Delivery Period
Delivery shall take place no earlier than the first calendar day of the delivery month and shall be completed no later than the last calendar day of the delivery month. All deliveries shall be made at as uniform as possible an hourly and daily rate of flow over the course of the delivery month.

Alternate Delivery Period
An Alternate Delivery Procedure is available to buyers and sellers who have been matched by the Exchange subsequent to the termination of trading in the spot month contract. If buyer and seller agree to consummate delivery under terms different from those prescribed in the contract specifications, they may proceed on that basis after submitting a notice of their intention to the Exchange.

Exchange of Futures For, or in Connection with, Physicals (EFP)
The commercial buyer or seller may exchange a futures position for a physical position of equal quantity by submitting a notice to the Exchange. EFPs may be used to either initiate or liquidate a futures position.

Quality Specifications
Pipeline specifications in effect at time of delivery.

Position Limits
7,000 contracts for all months combined, but not to exceed 1,000 in the last three days of trading in the spot month or 5,000 in any one month.

Margin Requirements
Margins are required for open futures and short options positions. The margin requirement for an options purchaser will never exceed the premium paid.

Trading Symbols
Futures: NG
Options:ON