UNIVERSITY OF CALIFORNIA AT BERKELEY

Department of Economics

Berkeley, California 94720

Working Paper No. 92-192

Are Futures Margins Adequate?

Roger Craine

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April 1992

Key words: Margin, default option, futures

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Abstract

This paper presents an analytic derivation of the market value of the clearinghouse performance guarantee and an empirical evaluation of the adequacy of the futures market margin system. The value of the performance guarantee on a long position in a futures contract equals the value of a put option. The guarantee is analytically equivalent to a third party debt guarantee. The value of the performance guarantee on a short position in a futures contract equals the value of a call option. The clearinghouse charges no explicit premium for the default option. Margin committees implicitly price the guarantee by setting the margin and settlement interval. A prudent margin system sets the market value of the default option to zero.

The option value provides a natural metric to evaluate the adequacy of the margin system. I examine the adequacy of the futures market margins on the December S&P500 futures contract during October 1991 and October 1987. October 1991 is a "typical" month. In October 1991 the value of the default option equals zero. October 1987 is not a typical month. In October 1987 the market experienced the greatest price volatility since the Chicago Mercantile Exchange opened in 1919. For the first half of October 1987 the market value of the default option was close to zero. The market value of the default option for the day of the crash, however, reached 5% of the price of the futures contract. And it stayed significantly above zero for the rest of the week. Futures market margin committees responded to the unprecedented increase in price volatility by tripling the margin with a rapid sequence of increases and by demanding intra-day settlements on the most volatile days. By the end of the month the default option again had no value.

The results indicate that the margin polices are sound. Zero, or very low values, of the default option are consistent with the fact that there has never been a clearinghouse failure.

[1] I thank Paul Kupiec and Merton Miller for comments.

Introduction

Large volume anonymous trading in futures contracts could not exist without a credible clearinghouse performance guarantee. A futures contract commits an agent to buy, or sell, a commodity at a future date at a price agreed upon today. Settlement (delivery and payment) takes place at the contract expiration date. Without additional restrictions, eg, trader liability or reputation, one of the parties always will default on the contract since the market value of the underlying commodity (almost surely) will not equal the futures price at the expiration date. On the London Metal Exchange, where participants are not protected by a clearinghouse guarantee, only principals trade.

Futures market clearinghouses guarantee the performance of all contracts so traders do not have to evaluate their trading partner.[2] Traders buy from or sell to the clearinghouse. If one side of a trade defaults the clearinghouse fulfills the obligation. The guarantee isolates each contract from other traders' actions. The guarantee transfers default risk to the clearinghouse.

This paper presents an analytic derivation of the market value of the clearinghouse performance guarantee and an empirical evaluation of the adequacy of the futures market margin system.

Merton (1977) showed the fair market value of a third party debt guarantee, eg, deposit insurance, equals the value of a put option. I extend Merton's analysis to value the clearinghouse

[2] Actually the clearinghouse guarantees the performance of clearing members. Other trades are executed through clearing members. See Edwards (1984) and Rutz (1989) for excellent detailed descriptions of the actual margin and clearing mechanism.

performance guarantees as options. In a debt contract only the borrower has the option to default. In a futures contract either side can default. The value of the performance guarantee on a long position in a futures contract equals the value of a put option. The guarantee is equivalent to a debt guarantee. The value of the performance guarantee on a short position in a futures contract equals the value of a call option.

Futures market clearinghouse margin committees implicitly price the guarantee by selecting a margin and audit (and settlement) interval. The process of marking accounts to market effectively sets the maturity of the guarantee (and the futures contract) to the audit interval. The margin determines the "striking price" of the default option. Since clearinghouses do not charge an explicit premium for the guarantee, a prudent margin system sets the market value of the guarantee to zero.

Margin committees, made up of clearinghouse members, set the margin policy. No governmental body oversees or regulates the futures margin system. Underpricing the guarantee subsidizes traders and rewards excessive risk taking. Ultimately it leads to systematic clearinghouse losses that eventually undermine the credibility of the guarantee. In 1989 the Federal Savings and Loan Insurance Fund could not meet its obligations and in 1991 the Federal Deposit Insurance Corporation turned to Congress for support. In the wake of the 1987 stock market crash several proposals to turn margin setting authority over to a government regulator--the CFTC, the SEC, or the Federal Reserve Board--sprang up. The prestigious Brady Commission Report recommended a single agency have authority to set consistent margins across marketplaces to control speculation and financial leverage.

Previous efforts to judge the adequacy of margin requirements focused on the probability that a price change will exceed the margin. Figlewski (1984), Gay, Hunter, and Kolb (1986), and Fenn and Kupiec (1991) present models of optimal margin policies. These models, however, cannot directly address the question of whether or not the actual margin policies provide adequate protection. The models have no observable metric to judge what is adequate. Whether these probabilities are acceptable or not depends on the unobservable cost of contracting in the Fenn-Kupiec model and the margin committees' unobservable risk tolerance in the Figlewski, and Gay-Hunter-Kolb models. Warshawsky, in an excellent comprehensive empirical study of margins, defines an adequate margin as one that covers 98% of the price moves.

The option pricing methodology gives a natural economic metric, the market value of the guarantee, to judge the adequacy of the actual futures market margin policy. An actuarially sound system requires the price of the guarantee to equal or exceed the private value of the guarantee. Since there is no explicit default premium, an adequate margin system sets the value of the default option to zero.

Section 3 of the paper evaluates the adequacy of the futures market margins on the December S&P500 futures contract during October 1987 and October 1991. October 1991 is a "typical" month. In October 1991 the value of the default option equals zero. October 1987 is not a typical month. In October 1987 the market experienced the greatest price volatility since the Chicago

Mercantile Exchange opened in 1919. For the first half of October 1987 the market value of the default option was close to zero. The market value of the default option for the day of the crash, however, reached 5% of the price of the futures contract. And it stayed significantly above zero for the rest of the week. Futures market margin committees responded to the unprecedented increase in price volatility by tripling the margin with a rapid sequence of increases and by demanding intra-day settlements on the most volatile days. By the end of the month the default option again had no value.

The results indicate that futures market margin polices are sound. In normal times the default option has no value. In abnormal times the margin committees reacted quickly resetting the system's parameters to maintain the financial integrity of the exchange.

Section 1: Definitions

The Futures Contract

A long position in a futures contract commits an agent to purchase a commodity, say an asset A, at a fixed future date, T, at a price set today, say $F(0,T)$. The short side of the contract commits an agent to sell the asset at the contract price $F(0,T)$. Settlement--delivery and payment--takes place at the contract expiration date T. Without additional restrictions one side of the contract almost surely will default.

The Margin System

Margins give traders an incentive to perform. Traders post an initial margin (a performance bond) say M, when they enter a futures contract. Their positions are marked to market (ie, their accounts audited) at intervals, say τ, thereafter. At the audit the traders must post a variation margin, say MV, to compensate for changes in the market value of their account,

$$MV = F(t+\tau,T) - F(t,T). \tag{1}$$

If the trader suffers a loss[3] he must add the amount lost to the margin account. If he makes a gain he can withdraw the gain. If the trader does not meet the margin requirement the clearinghouse suspends his trading privileges and liquidates the account.[4]

The margin system makes the effective maturity of the futures contract the audit interval, τ. At the audit date the trader either realizes the gain (loss) or defaults.

If he posts (withdraws) the variation margin he effectively enters a new contract at the current futures price, ie, $F(t+\tau,T) \equiv MV + F(t,T)$. And, if the trader realizes the gain by covering his position the contract is actually terminated.

The trader also has the option to default. If the loss on the futures position exceeds the margin

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[3] A loss, of course, depends on whether the trader holds a long or short position. If the futures price increases a short position loses and a long position gains.

[4] This is a very simplified description of the margin rules. In fact, there are initial margins, and maintenance margins, and margins for speculators and hedgers. Some clearinghouses require margins on gross positions while others require margins on net positions. And some clearinghouses accept Government securities or bank letters of credit for margin. See Edwards or Rutz for excellent detailed descriptions of the actual mechanism. I calculate the maximum value of the default option using the minimum margin requirement.

it may be in the trader's interest to default.

The Performance Guarantee

Large scale anonymous trading cannot occur without a credible performance guarantee. Futures market clearinghouses guarantee the performance of all futures contracts precisely so that futures traders do not have to worry about the other party's performance. If a trader defaults, the clearinghouse performs.

Section 2: The Option Value of the Performance Guarantee

Merton (1977) showed that a third party debt guarantee, eg, Federal Deposit Insurance, decomposes a risky debt contract into two contracts. A credible guarantee makes the debt obligation a risk (default) free contract to the lender. The borrower retains the option to default with the default risk transferred to the guarantor. Merton showed the option to default on a debt contract is formally equivalent to a put option.

The futures market clearinghouse performance guarantee also decomposes the futures contract into a default free contract and an option to default. I show the option to default on a long position is equivalent to a put option and the option to default on a short position is equivalent to a call option.

Assumptions

I make the standard assumptions from option pricing theory:

A 1 (i) the logarithmic return on the asset follows a diffusion process with a constant variance, σ^2, (ii) a constant risk free rate, r_f, exists, (iii) markets are "perfect", and (iv) the asset neither pays dividends nor has carrying cost over the contract interval.

Most of the assumptions have been relaxed in the option pricing literature and could be relaxed here, eg, see Duffie and Stanton (1992). I maintain the stronger assumptions to parallel Merton's derivation.[5]

In addition, I assume,

A 2 (i) there are *no* penalties, or costs (except the loss of the margin) associated with default.

The counterfactual assumption of costless default means the calculated value of the default option is the maximum value.

Market Value of the Default Free Contract

The market value of the default free contract is simply the deferred value of the spot price, ie,

$$F(t,T) = e^{r_f(T-t)}A(t),\ t \in [0,T].$$

The guarantee induces the well known arbitrage relationship that the spot price equals the present

---

[5] I examine the applicability of the assumptions more closely in the empirical section. The actual maturity of the default option is either one day or 1/2 a day. Therefore, the assumptions that the volatility and interest rate are constant over such a short horizon is not a bad approximation even if volatility and interest rate are changing over time.

value of the futures price discounted at the risk free rate.[6]

Market Value of the Default Option

The guarantee assures the trader that he can buy (or sell) the asset at the futures price, but the guarantee does not force him to perform. The trader has an option to default.

A Long Futures Position

Consider the payoff to the buyer of a futures contract at the next audit. If the net profit on the futures contract, $\{F(t+\tau,T)-F(t,T)\}$ - M, exceeds the margin the trader either posts the variation margin or clears his position by selling the contract. But, if the loss on the contract is greater than the margin the buyer defaults. So at the audit date the total value of a buyer's payoff,

$$VL(t+\tau) = \{F(t+\tau,T) - F(t,T)\} + M + \max[0, \{F(t,T) - M\} - F(t+\tau,T)], \tag{3}$$

can be written as: the value of the payoff on a guaranteed contract, plus the margin, $\{F(t+\tau,T)-F(t,T)\} + M$, plus the payoff on a "put" option, $max[0, \{F(t,T)-M\}-F(t+\tau,T)]$ with a striking price $F(t,T)-M$.

Conceptually, when the trader defaults he "puts" the asset he is obligated to purchase to the clearinghouse at the striking price $F(t,T)-M$. The net loss to the trader is the margin which he forfeits. The clearinghouse who "wrote" the option bears the remainder of the loss, $F(t+\tau)$ -

[6] For example, see Duffie (1989) Chapter 1.

$\{F(t,T)\text{-}M\} < 0$, when it liquidates the traders position.

The famous Black-Scholes (1973) formula for a European put option written on a *futures contract*[7] with a striking price of $F(t,T)\text{-}M$ and a maturity of τ,

$$P(\tau) = \{F(t,T)-M\}e^{-r_f\tau}\Phi(y_2) - F(t,T)\Phi(y_1), \textit{ where:}$$

$$y_1 \equiv \frac{\ln\left(\frac{F(t,T)-M}{F(t,T)}\right) - \left(r_f + \frac{\sigma^2}{2}\right)\tau}{\sigma\sqrt{\tau}}, \tag{4}$$

$$y_2 \equiv y_1 + \sigma\sqrt{\tau},$$

gives the market value of the performance guarantee to the buyer of a futures contract. Here Φ denotes the cumulative normal distribution function.

Analytically the value of the performance guarantee for the long side of a futures contract is exactly the same as the value of deposit insurance as derived by Merton.[8] In effect, the buyer of a futures contract buys the asset on credit. The performance guarantee protects the seller from the buyer's default, so the seller accepts the risk free return on the deferred payment. The default

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[7] Black (1976) derived the pricing formula for options on futures. For application in this paper the diffusion process for the logarithmic returns on the futures equals the diffusion process for the logarithmic return on the asset minus the risk free rate, ie, $d(\log F) = d(\log A) - r_f dt$, so the extension is straight-forward.

[8] In fact the application of the option pricing methodology to value the futures market performance guarantee is somewhat cleaner than the option valuation of deposit insurance. Options on futures actually exist and the default option could be created by replication. The maturity of the futures performance option is observable and fairly regular. Bank examination intervals, in contrast, are irregular and closure rules are not well defined. Finally, the return on futures is observable while the return on bank assets is not.

premium equals the value of a put option.

A Short Position

Now consider the payoff to the seller of a futures contract at the next audit. If the seller's net profit on the futures contract, $\{F(t,T)-F(t+\tau,T)\} - M$, exceeds the margin the trader either posts the variation margin or clears the position by selling the contract. But, if the loss on the contract is greater than the margin the seller defaults. So at the audit date the total value of a seller's payoff,

$$VS(t+\tau) = \{F(t,T) - F(t+\tau,T)\} + M + \max[0, F(t+\tau,T) - \{F(t,T) + M\}], \tag{5}$$

can be written as: the value of the payoff on a guaranteed contract, plus the margin, $\{F(t,T)-F(t+\tau,T)\} + M$, plus the payoff on a "call" option, $max[0, F(t+\tau,T)-\{F(t,T)+M\}]$, with the striking price $F(t,T)+M$.

When the trader defaults he "calls" the asset he is obligated to deliver from the clearinghouse at the striking price $F(t,T)+M$. The clearinghouse who wrote the call option bears the loss, $\{F(t,T)+M\}-F(t+\tau,T)$, when it liquidates the traders position.

The Black-Scholes formula for a European call option with a striking price of $F(t,T)+M$ and maturity of τ, gives the market value of the performance guarantee for the short side of the futures contract.

The performance guarantee for the short side of a futures contract is also a "debt" guarantee. In effect, the seller borrows the asset for the life of the contract. The performance guarantee assures the buyer that the asset will be delivered at the expiration of the contract. So the buyer does not demand a default premium from the seller.

Section 3: An Evaluation of the of the Actual Pricing of the Guarantee

The clearinghouses rely primarily on a margin system to control their exposure to risk. However, clearinghouses also monitor the financial condition of their clearing members and sometimes impose trading limits and sanctions. In addition, futures accounts are not limited liability accounts.

The option pricing formula gives the least upper bound of the true unobservable market value of the guarantee to the trader. The private value of the guarantee cannot exceed the calculated value of the option, but for traders with large wealth and portfolios that are not too risky the value might be considerably less. If the option has private value[9] it is most valuable to traders with the lowest wealth and riskiest portfolios--ie, adverse selection exacerbates clearinghouse risk exposure from underpricing the guarantee. Margin committees choose a margin and audit (settlement) interval which sets the striking price and the maturity of the default options derived in Section 2. But clearinghouses do not charge an explicit premium for the default option.

[9] The private value of the guarantee is bounded below at zero.

Therefore, a prudent margin policy sets the calculated value of the options to zero.[10]

Evaluating the Black-Scholes option pricing formula requires an estimate of the variance of the (logarithmic) return on the futures contract and a proxy for the risk free interest rate. The remaining variables--the futures price, the margin, and the time to expiration--are observable.

I estimate the daily variance of the diffusion process by,

$$s^2 \equiv .360738(range)^2,$$

where the range is the natural log of the high price during the day minus the log of the low price, see Garman and Klass (1980). The estimator accentuates the intra-day volatility because it does not average across days. I use the estimate of the variance as the forward-looking rationally expected variance for that day. I proxy the risk free rate with the US Treasury bill rate[11] and use the hedging maintenance margin to calculate the striking price. Finally I choose the regular settlement interval on the Chicago Mercantile Exchange--daily before 1988 and twice daily after 1988--as the option maturity.

When I had a choice of input variables for the Black-Scholes formula I chose the variable that maximized the value of the option. I use the hedging margin which is lower than a speculator's

[10] Any zero option value policy is safe, but not necessarily optimal. Safe policies with lower margins, or less frequent audits reduce the cost of the margin system.

[11] The price of very short maturity options is not sensitive to small errors in the risk free rate. After all the daily rate is only about .01%.

margin and the maintenance margin is never higher than the initial margin. And I use the regular settlement interval even though the clearinghouse made occasional intra-day margin calls.

Evaluation

I use the calculated option values to examine the adequacy of the actual margin system during two Octobers: October 1991, a "typical" month and October 1987--the month with the most price volatility since the creation of the Chicago Mercantile Exchange. I calculate the option values of the guarantee for the (nearby) December S&P500 Futures Contract. This is a high volume contract that is popular with portfolio insurers and index arbitragers.

October 1991

October '91 was a typical month. The average of the daily estimates of the standard deviation of the return equals 0.61% with a standard deviation of 0.20%. The margin averaged 4.6% of the contract price. These are fairly close to Kupiec's (1991) estimates for a daily sample from 1982 through 1989. Kupiec found an average margin of 4.0% and his estimate of average daily standard deviation of the return (using the same unsmoothed range estimator) is 0.8% with a standard deviation of 0.60%. Settlement took place twice daily in October 1991.

The value of the default option for October 1991 is zero (zero to machine rounding error). And the probability that the price change will exceed the margin (ie, the probability that the option will be in the money) is essentially zero. See Table 1 in the appendix for details. The margin policy in the typical month of October 1991 was adequate; in fact, it was quite conservative.

October 1987

October 1987 was not a typical month. Trading in the S&P500 futures contract was very heavy during the 1987 crash and the price fluctuations were extreme. The unprecedented close to close 40% decline in the futures price on October 19 was much larger than the well-publicized 25% drop in the spot S&P500 index. The extreme price volatility and heavy trading volume in October 1987 stretched every system at the exchanges and clearinghouses to the breaking point.

The minimum estimated standard deviation of the return, 0.51%, occurred the first day of October 1987. The maximum estimated standard deviation of the return skyrocketed to 18.41% on the day of the crash, October 19th. The monthly average of the return volatility (estimated standard deviation of the returns) is 4.3%--seven times the October '91 monthly average volatility.

Figure 1 plots the values of the default option[12], the probability the option will be in the money--ie, the ex ante probability the price change will exceed the margin, and the margin. The margin and the option price are expressed as fractions of the futures price.

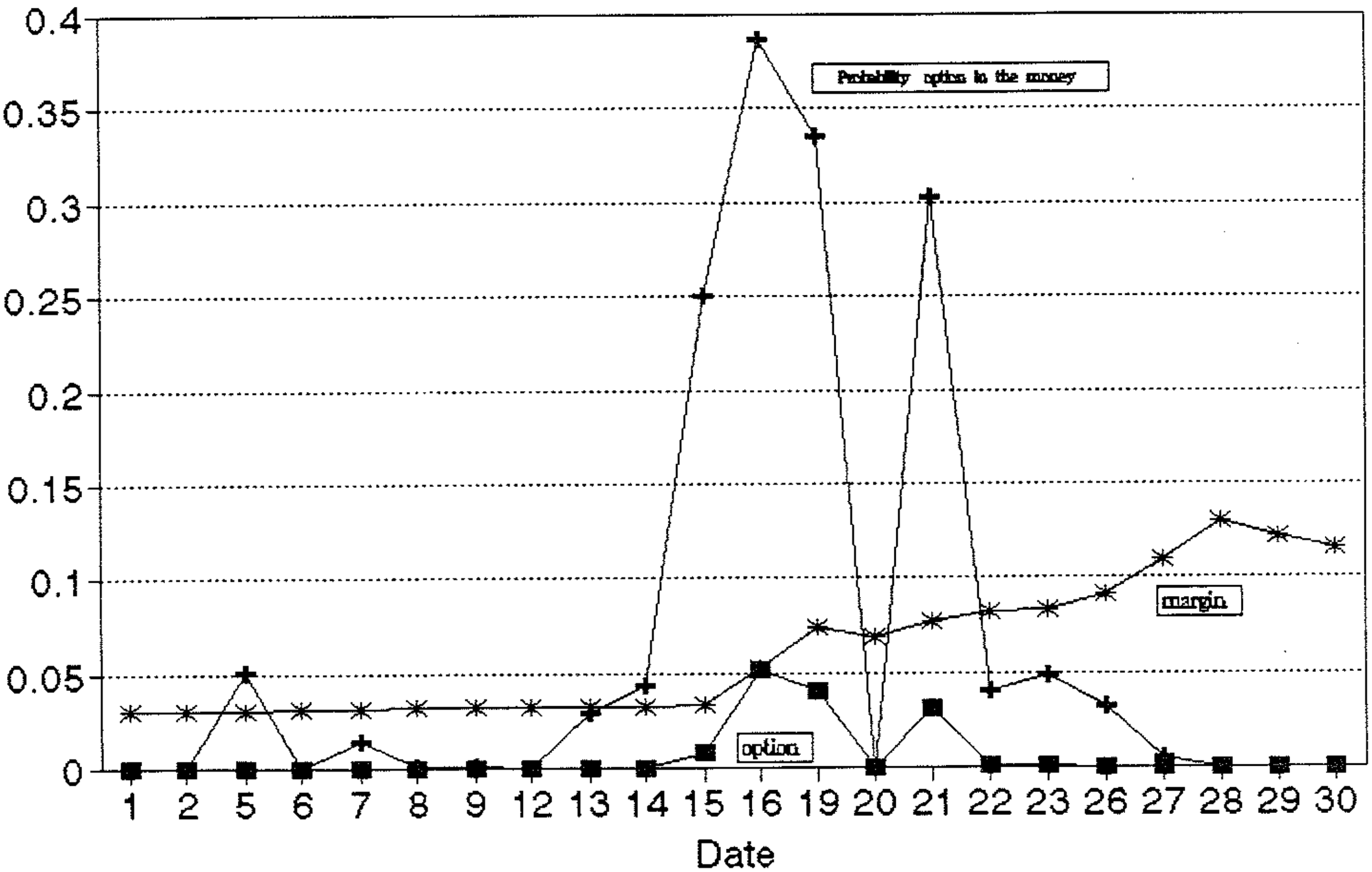
INSERT FIGURE 1

The line marked with +s shows the ex ante probability that the price change will exceed the margin, or the probability that the option will expire in the money. This line dramatically illustrates the extreme volatility.

[12] Figure 1 gives the value of the call option on a short contract which slightly exceeds the value of a put option.

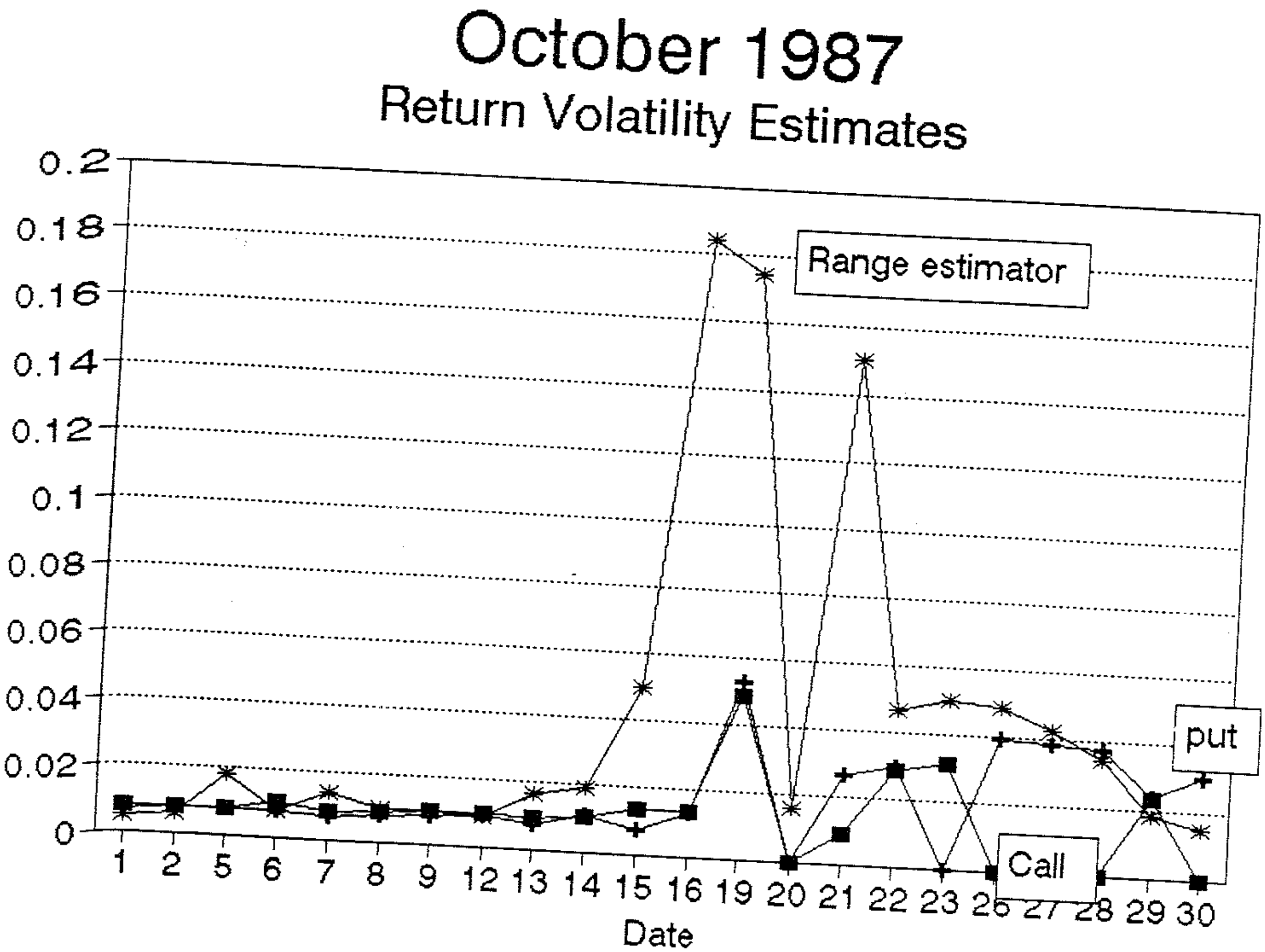
October 1987

Option Values, Margins Probabilities



The probability line also shows why it is hard to judge the adequacy of a margin system by simply looking at the probability that price changes will exceed the margin. The bottom line marked with ■s shows the default option values. The option values are nearly zero (see Table 2 in the appendix) except for the week of the crash and Thursday and Friday of the preceding week. For example, the 3% realized price change on Tuesday the 6th gave an ex ante probability (using the forward looking range estimator of the variance) that a 5% chance existed that the price change would exceed the margin. But the default option value was only .04% (four basis points) of the futures price. The ex ante probability of insolvency for October 19 was almost 40% and the value of the option jumped to 5% of the futures price. The following day the probability that the price change would again exceed the margin was 1/3, and the value of the option 4% of the futures price. By the end of the week, however, the increased margin and decreased price volatility reduced the option values to 13 basis points. And the week following the crash the value of the default option returned to zero.

The calculated option values support the view that the clearinghouses acted quickly and prudently to maintain the financial integrity of the Exchange. The margin committees responded to the unprecedented increase in price volatility by tripling the maintenance margin from $5000 (roughly 3% of the contract value) to $15000 (10% of the contract value--see Table 3 in the Appendix) in a rapid sequence of $2500 jumps. The CME also demanded intra-day settlements during the most volatile days, three on the 19th, one on the 21st and two on the 26th. Figure 1 overstates the option values by calculating values for options with a maturity of one day. Recalculating the option value for the 19th with a maturity of 1/4 of a day reduces the option


October 1987
Return Volatility Estimates
0.2
0.18
0.16
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
Range estimator
put
Call
1 2 5 6 7 8 9 12 13 14 15 16 19 20 21 22 23 26 27 28 29 30
Date

because it does not time-average.

Figure 2 shows the volatilities implied by November options on the December S&P500 futures contract and the volatilities from the range estimator.

INSERT FIGURE 2

During the first half of October the implied volatilities from puts and calls and the estimated volatility are essentially the same (Table 5 in the appendix has the precise values.) During the second half of October the estimated volatilities are consistently larger than the volatilities implied by the traded options. On October 16 the forward looking range estimator gives an estimate of the volatility that is 13 times as large as the implied volatility. Of course the November option expires on November 20 so the implied volatilities cover a longer interval than the one-day volatilities in the default option. Table 5 (in the appendix) shows the implied volatilities from the October option which expired on Friday the 16th. Again the estimated volatilities for the first half of the month are very close to the implied volatilities. But as the market volatility increases in the week preceding the crash (when the October option maturity is less than 3 days) the estimated volatilities again substantially exceed the implied volatilities.

The inferences from traded options about the market's expectations of volatility give no indication that the range estimator underestimates perceived volatility.

Summary and Conclusion

This paper presented an analytic derivation of the market value of the clearinghouse performance guarantee and an empirical evaluation of the adequacy of the futures market margin system. I extended Merton's analysis of the value of third party debt guarantees to value the futures market performance guarantee. The value of the guarantee on a long futures position is equivalent to the value of a put option. The value of the guarantee on a short futures position is equivalent to the value of a call option.

The value of the option provides a natural metric to measure the adequacy of the margin system. The probability that price changes will exceed the margin--the measure used in other studies--has no natural metric to determine an "acceptable" probability. A prudent margin policy sets the value of the default option to zero.

I evaluated the adequacy of the futures market margin system by calculating the default options values for October 1991 and October 1987 on the December S&P500 futures contract. October 1991 was a typical month. The default option had no value. Prices during October 1987 were more volatile than any other month since the CME opened. Margin committees quickly responded to the unprecedented increase in volatility with a sequence of margin increases and intra-day settlements on the most volatile days. The default option values were essentially zero except for the week of the October 19 when prices fell 40% in a single day and ended the week 20% lower. The results indicate that margins are adequate.

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APPENDIX

Table 1: October 91--Value of the Default Option

Date	Default Option Value	Probability in the Money	Margin Fraction	Estimated Sigma
1	0.0000%	0.0000%	4.60%	0.0051
2	0.0000%	0.0000%	4.62%	0.0065
3	0.0000%	0.0000%	4.67%	0.0083
4	0.0000%	0.0000%	4.71%	0.0047
7	0.0000%	0.0000%	4.71%	0.0038
8	0.0000%	0.0000%	4.71%	0.0078
9	0.0000%	0.0000%	4.76%	0.0077
10	0.0000%	0.0000%	4.71%	0.0030
11	0.0000%	0.0000%	4.70%	0.0087
14	0.0000%	0.0000%	4.63%	0.0093
15	0.0000%	0.0000%	4.59%	0.0053
16	0.0000%	0.0000%	4.56%	0.0063
17	0.0000%	0.0000%	4.57%	0.0030
18	0.0000%	0.0000%	4.56%	0.0053
21	0.0000%	0.0000%	4.59%	0.0067
22	0.0000%	0.0000%	4.62%	0.0042
23	0.0000%	0.0000%	4.62%	0.0075
24	0.0000%	0.0000%	4.66%	0.0060
25	0.0000%	0.0000%	4.67%	0.0076
28	0.0000%	0.0000%	4.61%	0.0086
29	0.0000%	0.0000%	4.58%	0.0042
30	0.0000%	0.0000%	4.57%	0.0025
31	0.0000%	0.0000%	4.58%	0.0089

Table 2: October 1987--Value of the Default Option

Date	Default Option Value	Probability in the Money	Margin Fraction	Estimated Sigma
1	0.0000%	0.0000%	3.01%	0.0051
2	0.0000%	0.0001%	3.02%	0.0064
5	0.0425%	5.0246%	3.02%	0.0184
6	0.0000%	0.0065%	3.13%	0.0082
7	0.0081%	1.3986%	3.12%	0.0142
8	0.0004%	0.1180%	3.17%	0.0104
9	0.0003%	0.0875%	3.20%	0.0102
12	0.0000%	0.0201%	3.21%	0.0091
13	0.0217%	2.9722%	3.17%	0.0168
14	0.0377%	4.3392%	3.28%	0.0191
15	0.7784%	25.0845%	3.35%	0.0499
16	5.1712%	38.6389%	5.31%	0.1841
19	4.0930%	33.4785%	7.44%	0.1744
20	0.0000%	0.0013%	6.94%	0.0165
21	3.1091%	30.3339%	7.74%	0.1504
22	0.0951%	4.0533%	8.18%	0.0469
23	0.1257%	4.9119%	8.30%	0.0502
26	0.0796%	3.2226%	9.08%	0.0491
27	0.0109%	0.5073%	10.94%	0.0425
28	0.0002%	0.0095%	12.97%	0.0348
29	0.0000%	0.0000%	12.21%	0.0188
30	0.0000%	0.0000%	11.57%	0.0015

Table 3: October 1987--Futures and Spot Market Prices

Date	Spot Price	Futures Open	High	Low	Settle	Margin
Oct 1	$327.33	$326.50	$331.80	$326.05	$331.70	$5,000.00
2	$328.07	$331.00	$333.00	$330.20	$331.35	$5,000.00
5	$328.08	$331.10	$331.80	$328.30	$330.80	$5,000.00
6	$319.22	$329.40	$329.70	$319.75	$319.85	$5,000.00
7	$318.54	$319.40	$322.05	$317.70	$320.65	$5,000.00
8	$314.16	$320.60	$321.20	$313.70	$315.80	$5,000.00
9	$311.07	$315.20	$317.05	$311.60	$312.20	$5,000.00
12	$309.39	$310.95	$313.70	$308.40	$311.60	$5,000.00
13	$314.52	$314.10	$317.00	$312.25	$315.65	$5,000.00
14	$305.23	$312.20	$313.45	$304.80	$305.00	$5,000.00
15	$298.08	$303.30	$307.60	$297.95	$298.25	$5,000.00
16	$282.70	$300.50	$301.00	$277.00	$282.25	$7,500.00
19	$224.84	$264.00	$269.00	$198.00	$201.50	$7,500.00
20	$236.83	$221.00	$242.00	$181.00	$216.25	$7,500.00
21	$258.38	$242.00	$259.50	$252.47	$258.25	$10,000.00
22	$248.25	$202.00	$250.50	$195.00	$244.50	$10,000.00
23	$248.22	$240.00	$253.00	$234.00	$241.00	$10,000.00
26	$227.67	$228.00	$237.00	$218.00	$220.25	$10,000.00
27	$233.19	$242.00	$242.00	$223.00	$228.60	$12,500.00
28	$233.28	$220.00	$234.00	$218.00	$231.25	$15,000.00
29	$244.77	$237.00	$249.00	$235.00	$245.70	$15,000.00
30	$251.79	$253.00	$260.00	$252.00	$259.35	$15,000.00
Nov 2	$255.75	$255.00	$257.90	$251.50	$257.75	$15,000.00

Table 4: Volatility Implied by November 87 Options

Date	Futures Price	Strike Price	Nov Call Price	Nov Put Price	Implied Sigma(Call)	Implied Sigma(Put)	Estimated Sigma
1	$331.70	$320.00	$16.40	$4.00	0.0078	0.0071	0.0051
2	$331.35	$320.00	$16.00	$4.80	0.0078	0.0080	0.0064
5	$330.80	$320.00	$15.35	$4.65	0.0079	0.0082	0.0184
6	$319.85	$320.00	$10.35	$9.20	0.0107	0.0078	0.0082
7	$320.65	$320.00	$9.20	$8.25	0.0089	0.0073	0.0142
8	$315.80	$320.00	$6.80	$10.95	0.0092	0.0079	0.0104
9	$312.20	$320.00	$5.45	$13.20	0.0098	0.0088	0.0102
12	$311.60	$320.00	$5.10	$13.45	0.0102	0.0094	0.0091
13	$315.65	$320.00	$6.45	$10.00	0.0097	0.0077	0.0168
14	$305.00	$320.00	$3.05	$17.95	0.0107	0.0113	0.0191
15	$298.25	$315.00	$4.10	$15.80	0.0136	0.0073	0.0499
16	$282.25	$290.00	$6.20	$14.00	0.0135	0.0131	0.1841
19	$201.50	$290.00	$2.90	$91.00	0.0491	0.0529	0.1744
20	$216.25	$230.00					0.0165
21	$258.25	$260.00	$5.00	$16.75	0.0092	0.0272	0.1504
22	$244.50	$260.00	$9.30	$24.80	0.0290	0.0300	0.0469
23	$241.00	$255.00	$10.50		0.0315		0.0502
26	$220.25	$230.00		$23.00		0.0398	0.0491
27	$228.60	$230.00		$18.20		0.0389	0.0425
28	$231.25	$230.00		$16.00		0.0375	0.0348
29	$245.70	$260.00	$5.50	$19.50	0.0237	0.0245	0.0188
30	$259.35	$260.00		$14.80		0.0301	0.0151
					precrash	average	volatility
					0.0100	0.0130	0.0107
					monthly	average	volatility
					0.0203	0.0249	0.041328

Table 5: Volatility Implied by October 87 Options

Date	Futures Price	Strike Price	Call Price	Put Price	Implied Sigma(call)	Implied Sigma(put)	Estimated Sigma
0	$325.85	$315.00	$12.45	$1.65	0.0080	0.0108	0.0051
1	$331.70	$320.00	$13.05	$1.35	0.0077	0.0106	0.0064
2	$331.35	$320.00	$12.45	$1.15	0.0069	0.0101	0.0184
5	$330.80	$320.00	$11.00	$1.00	0.0017	0.0103	0.0082
6	$319.85	$320.00	$4.25	$4.40	0.0095	0.0099	0.0142
7	$320.65	$310.00	$11.55	$0.90	0.0086	0.0111	0.0104
8	$315.80	$310.00	$7.60	$1.80	0.0098	0.0113	0.0102
9	$312.20	$310.00	$4.80	$2.60	0.0095	0.0103	0.0091
12	$311.60	$310.00	$3.95	$2.35	0.0106	0.0113	0.0168
13	$315.65	$310.00	$6.35	$0.70	0.0094	0.0107	0.0191
14	$305.00	$310.00	$1.00	$5.60	0.0131	0.0115	0.0499
15	$298.25	$310.00	$0.10	$11.85	0.0153	0.0176	0.1841
16	$282.25	$290.00		$7.75		0.0143	0.1744
					average	average	average
					0.00916103	0.0115148	0.0405

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