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## Article

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Journal of Risk and Financial Management

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*Suggested Citation:* Mitchell, John B. (2010) : Soybean futures crush spread arbitrage: Trading strategies and market efficiency, Journal of Risk and Financial Management, ISSN 1911-8074, MDPI, Basel, Vol. 3, Iss. 1, pp. 63-96,  
<https://doi.org/10.3390/jrfm3010063>

This Version is available at:

<https://hdl.handle.net/10419/178525>

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# **Soybean Futures Crush Spread Arbitrage: Trading Strategies and Market Efficiency**

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## **ABSTRACT**

This paper revisits the soybean crush spread arbitrage work of Simon (1999) by studying a longer time period, wider variety of entry and exit limits, and the risk-return relationship between entry and exit limits. The lengths of winning and losing trades are found to differ systematically, with winning trades significantly shorter on average than losing trades. Exiting trades near the 5-day moving average is shown to improve trade performance relative to a reversal of sign and magnitude from the entry spread. These results lead to trading rules designed to prevent lengthy trades; however, the profitability of trading rules is found to be unstable.

**KEYWORDS:** Futures, Spread, Arbitrage, Market Efficiency, Trading Strategies

**JEL CLASSIFICATION:** G13

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## **1. INTRODUCTION**

Soybean (S), soybean meal (SM), and soy oil (BO) futures contracts are traded on the Chicago Board of Trade (CBOT). This paper explores the relationship between these three contracts, commonly referred to as the crush spread. The soybean crush spread provides an interesting opportunity for exploring market efficiency. The relatively stable relationship between soybeans and the amount of meal and oil that are produced when the beans are crushed results in predictable value relationships between the relevant futures contracts.

The crush spread is employed both by speculators betting on a widening or narrowing of the relationship between the contracts and by other market participants, such as soybean crushing mill owners, with an economic stake in the relative prices of the three commodities. A long crush refers to buying the meal and oil and selling the beans. Speculators would employ this trade when the spread is narrow relative to normal levels and the value of meal and oil is expected to rise relative to the value of beans. This trade minimizes the risk associated with general price movements of the three contracts and allows speculators to focus on the relationship between the contracts. Similarly, a wide spread could be exploited by selling the meal and oil and buying the beans.

Owners of crushing mills can employ the same trades to lock in profit margins by guaranteeing the relative value of their final products (meal and oil) relative to their principal input (beans). Mill owners would, for example, sell the spread (sell meal and oil and buy beans) when the spread is large.

The crush spread is calculated here based on a naïve 1:1:1 relationship, consistent with earlier studies.

$$\text{Crush Spread} = (\text{SM} \times 100) + (\text{BO} \times 600) - (\text{S} \times 50) \quad (1)$$

Where SM is the price of Soybean Meal in dollars per ton, BO is the price of Soybean Oil in dollars per 100 pounds, and S is the price of Soybeans in dollars per 100 bushels. The

coefficients convert the unit prices into roughly equivalent amounts based on the contract sizes of 5,000 bushels for soybeans, 60,000 pounds for soy oil and 100 tons for soybean meal.

For example: If prices on day X are SM = \$220 per ton, BO = \$25 per 100 pounds, and S = \$710 per 100 bushels; then the dollar value of the crush spread is:

$$\text{Crush Spread Day X} = (\$220 \times 100) + (\$25 \times 600) - (\$710 \times 50) = \$1,500. \quad (2)$$

Assume that the trader expects the crush spread to narrow and therefore sells meal and oil and simultaneously buys beans. On day X+1 SM = 218, BO = 24.5, and S = 708.

$$\text{Crush Spread Day X} = (\$218 \times 100) + (\$24.5 \times 600) - (\$708 \times 50) = \$1,100. \quad (3)$$

The narrowing of the crush spread results in a \$400 profit (\$1,500 - \$1,100) when the trader reverses their positions by buying back the meal and oil and simultaneously selling beans.

This research builds upon earlier studies as to how efficient the futures markets are in pricing these contracts. Various trading strategies based on mean reversion are tested over a 22-year period from 1984-2006. Techniques such as stopping transactions short of full reversion and truncating trade length are explored.

## **2. REVIEW OF LITERATURE**

Simon (1999) studies the soybean futures crush spread over the period January, 1985 through February, 1995. He finds that the crush spread tends to revert toward its 5-day moving average with a half-life of deviations of about 3 days. He proposes trading rules to take advantage of this relationship. Simon studies entry and exit limits of \$100, 200 and 300 above and below the recent 5-day moving average. Trades are reversed when the spread reaches a level equal to, but of opposite sign, to the initiating trigger. For example, a trade to sell the spread is initiated when the spread is \$100 larger than its 5-day moving average and reversed when the spread is \$100

less than its 5-day moving average. This procedure counts on a positive spread (relative to the recent average) becoming a negative spread (again relative to its trailing average).

Trades prove profitable after adjustment for transaction costs (\$103.50 per round-trip trade) with the average profit ranging from \$27 to \$355 for long trades as the limits are increased from \$100 to \$300 and similarly from \$33 to \$185 for short trades. Approximately two thirds of all trades prove profitable. Trading rules based on a regression-derived fair market value improve both the percentage of profitable trades and average profit but reduce the number of trading opportunities to as few as 3 over a 10-year period. Fair-value considerations also add to the complexity of determining when to initiate a trade. Simon also reports that the average length of winning and losing trades does not differ significantly.

Rechner and Poitras (1993) examine intraday trading opportunities in the soy complex during the period of 1978-1991. They find that naïve spread reversal trades are profitable when a filter is applied. The profit per trade increases, after transaction costs of 1.5 cents per bushel, from a loss of .35 cents per bushel with no filter to +.35, 1.02, and 1.74 respectively at filters of 1, 2, and 3 cents per bushel. The percentage of profitable trades increases from 39.6% to 69.0% over the same range. The coefficient of variation, derived from their results, is 8.49, 2.83, and 2.30 for the same three filters. They also report significant positive skewness (near 1) and kurtosis (6 to 7) of the distribution of trade results.

Johnson, Zulauf, Irwin, and Gerlow (1991) explore various fixed-length trades for the soybean crush spread over the period 1966-1988. Deviations of an implied net crushing margin from its 60-day moving average potentially trigger trades on the 15<sup>th</sup> of each month. Trade lengths of 1.5, 3.5, 5.5, 7.5, and 9.5 months are studied. Transaction costs of \$207 are deducted from profits for trade lengths of 5.5 months or less and \$236 for longer trades. Trades are reversed on the 1<sup>st</sup> trading day of the month.

Johnson et al., (1991) find that longer trade lengths and larger filters (deviations from recent average) result in larger profits and a higher percentage of profitable trades. While 1.5 month trades result in an average loss of \$156, profit increases to \$3, \$241, \$235, and \$418 as

the trade length increases. Filters of 20 cents result in near 100% profitable trades, but very few, 2 to 24, trades over the study period. Filters of 10-20 cents result in 38% to 60% profitable short (sell the spread) trades and 57% to 65% profitable long trades, but still only 10 to 39 trades over the study period. Smaller filters are even less successful. Traders are left with the choice of very few, but profitable, trades at high filters, or a low probability of success and high coefficient of variation at lower filters.

Numerous authors provide results from other financial and commodity futures markets. Barrett and Kolb (1995) find little evidence of regularities that would lead to profit-making opportunities in a wide variety of intra and inter-market commodity spreads. Girma and Paulson (1999) test various magnitude deviations, measured in standard deviations, from the moving average for the petroleum crack spread and utilize movement beyond the 5-day moving average for an exit trigger. Castelino and Vora (1984) find that volatility of the spread increases with spread length. Poitras (1998) discusses whether the existence of profits necessarily means market inefficiency due to variations in transaction costs and liquidity constraints, especially in longer maturity contracts. He tests fixed length trades in the TED spread during the period 1983-1991 and finds a small number of profitable (before transaction costs) trades (generally 1 to 4 per year), improvement in profit and percentage of profitable trades if a filter is applied, and that the day of the month that trades occur affects profitability. Ma and Soenen (1988) find positive risk-adjusted profits in the gold – silver spread over the period 1976-1986 using next-day prices to ensure market access. They employ 28 and 30-day moving averages and standard deviation based filters to generate approximately 20 trades per year with more than 50% profitable. A 30-day moving average and .5 standard deviation of the spread filter result in an average (un-weighted) coefficient of variation of 3.04 and 61% profitable trades. Wahab, Cohn, and Lashgari (1994) also study the gold-silver spread and find negative returns after transaction costs. Some infrequent moving average signals result in highly risky profits. Carter (1989) studies spreads between liquid versus illiquid futures contracts (corn versus barley, soybeans versus rapeseed, and Chicago versus Toronto T-bonds) and finds mixed results with a limited number of transactions. Only the T-bond spread proves profitable. Elfakhani and Wionzak (1997) update the Carter study and find limited statistically insignificant arbitrage opportunities.

More recently, Dunis, Laws, and Evans (2006) update the work of Butterworth and Holmes (2002). Dunis et al., (2006) find that a moving average model outperforms a fair value model for petroleum inter-market spreads from 1995-2004. They find annualized returns as high as 26.15% using a correlation filter and including transaction costs. Similarly, Haigh and Holt (2002) find that a multivariate GARCH model increases the effectiveness of crack spread hedging.

The interest in the risk reduction and arbitrage opportunities in spread trading is exemplified by the recent introduction of spread futures on the Chicago Board of Trade. This development is chronicled by Cuny (2006). The CBOT introduced Soybean Crush Options, further emphasizing the need existing in the market for understanding the behavior of the soybean crush spread.

### **3. MOTIVATION FOR STUDY**

This study differs from earlier research in the five ways. First, this study reverses trades at, or near, its 5-day moving average rather than at a spread of equal but opposite sign as the opening limit. Simon (1999) finds mean reversion. However, mean reversion does not necessarily imply that the spread will continue beyond equilibrium in an oscillating manner. By choosing closing limits short of equilibrium, this study attempts to increase the percentage of profitable trades and reduce the standard deviation of profit; albeit at the possible expense of reduced profit.

Second, truncating trades is explored as a way to avoid adverse trade results. This truncation is based on the observation, discussed in the results section, that losing trades are, on average, significantly longer than winning trades.

Third, a much longer time period is studied. This study covers approximately 22 years while Simon studies 10 years. Some trading strategies result in relatively few trades per year and thus a larger sample of simulated trades is produced. This study also serves as an out-of-sample replication of Simon. When the results are divided into shorter time intervals it is revealed that

strategy results can vary substantially in different time intervals. This demonstrates the importance of a long study period.

Fourth, a larger number of measures of performance are studied in an attempt to better understand the nature of any arbitrage opportunities.

Fifth, trading strategies are based only on deviations from the recent crush spread and are derived from futures market data readily available to traders. Simon employs a fair value concept based on seasonal adjustment of the crush spread using regression techniques. While effective, Simon's fair value concept cannot be calculated as quickly by traders as the actual crush spread.

## **4. DATA**

Soybean, Soybean Meal, and Soybean Oil futures contract prices collected from Commodity Systems Inc. are studied for the period from June 4, 1984 through April 7, 2006. The closing price for each trading day is employed to calculate the crush spread with the contracts rolled over on the first day of the month before expiration. All three contracts have January, March, May, July, August, and September expirations. Soybeans also have a November contract while oil and meal have October and December contracts. The same contract expirations are employed for each commodity with the exception of trading November soybeans against December oil and meal. For example, on the first trading date in April, the May contracts are rolled over to the June contract. On the first trading date in August, the September contract in soybeans is rolled over to the November contract and the oil and meal contracts are rolled over to the December contracts. This methodology is the same as that employed by Simon.

## **5. METHODOLOGY**

Trades are opened when the crush spread deviates from its most recent 5-day moving average by amounts ranging from \$200 to \$400. If the crush spread exceeds the specified amount, sell the spread i.e., sell oil and meal and buy soybeans. Similarly, if the crush spread falls below the 5-



day moving average by the specified amount, buy the spread i.e., buy oil and meal and sell soybeans.

Transactions are reversed (closed) if the deviation from the 5-day moving average becomes less than specified amounts ranging from zero to \$200. This trade reversal rule differs from the rule employed by Simon. Simon tests for movement beyond the 5-day moving average. Mean reversion does not necessarily imply that the spread will do anything more than revert towards the mean. There is no reason to expect that the spread will continue in an oscillating manner beyond the 5-day moving average. Once exceeding its recent average there should be immediate pressure to move back toward that average. Therefore, it is unreasonable to expect, and indeed count upon, continued movement away from the 5-day average. Closing limits short of reverting to the 5-day moving average are tested to determine if stopping short of the average improves the percentage of profitable trades and other trade characteristics.

Closing transactions on rollover dates are triggered based on the previous contracts while opening transactions on those dates are triggered based on the new contracts. Therefore, the 5-day moving average is always calculated based on the previous 5 days for the same contract expiration month being employed to trigger a transaction.

Only one trade is allowed to exist at any given point in time. New positions are not created until existing trades have been reversed to isolate the effects of particular opening limits. Secondly, the use of symmetric (+/-) opening limits combined with smaller closing limits precludes the establishment of long positions while short positions, or vice versa, are outstanding.

## **6. RESULTS**

### ***6.1. Results with Transaction Costs***

Results are presented with the same \$103.50 transaction costs employed by Simon for both short and long trades for each combination of trade limits. Although brokerage fees fell over the study

period, the bid-ask spread, which is the largest component of the transaction cost, was relatively stable. For ease of reporting the trade limits are symmetric. Long and short trades use the same limit with opposite sign, and limits are reported as opening/closing. Results consist of the number of trades, average profit, standard deviation of profit, coefficient of variation, percentage of profitable trades, maximum profit and loss, average length of trade, average length of profitable and unprofitable trades, maximum length of profitable and minimum length of unprofitable trades, and maximum trade length.

### ***6.1.1. Number of Trades***

The number of trades over the 20-year study, Table 1, varies from a low of 70 in the case of 400/0 thru 40 (an opening trade limit of 400 and a closing limit of anywhere between 0 and 40) to a high of 994 for 100/80. The effects of increasing the closing limit are relatively modest. For example, at an opening limit of 400, raising the closing limit from 0 to 200 only increases the number of trades by 6% (from 70 to 74) while at an opening limit of 220, raising the closing limit to 200 increases the number of trades by 20% (from 285 to 341). Closing limits of half the size of opening limits (e.g., 400/200) result in a 6 - 13% increase in trades relative to a return to the 5-day moving average (e.g., 400/0). The effect is less at higher opening limits. The increase in the number of trades as the closing limit is increased is a result of completing transactions more rapidly and therefore clearing the way for additional trades.

The number of trades is more sensitive to the opening limit. An increase of 20 in the opening limit results, on average, in a 15% reduction in the number of trades when the closing limit is zero. It is important to note that the reported results are for a 20-year period. Even the maximum number of 994 trades amounts to no more than one trade every 7 days; and at the highest limits only one trade every 104 days. Unless trades prove very profitable, only an automated trading system could prove economically worthwhile.

### ***6.1.2 . Average Profit***

Average profit, Table 2, ranges from a low of -\$41.88 at limits of 100/80 to \$122.17 at 400/80. The maximum profit for each opening limit generally occurs at, or near, a closing limit of zero. Closing limits half as large as opening limits, result in a 24 - 65% decrease in average profit relative to a closing limit of zero at opening limits above 240, where such a comparison becomes meaningful. Increasing the opening limit increases average profit most rapidly between 140 and 320 with more modest increases at each end of the range.

### ***6.1.3 . Standard Deviation of Profit***

The standard deviation of profit, Table 3, ranges from a low of \$219 at 100/80 to a high of \$595 at 400/0. The standard deviation increases as the opening limit is increased and as the closing limit is decreased. The standard deviation is less sensitive to changes in the closing limit, at least at low levels of the closing limit, when the opening limit is large. This suggests that closing limits near zero may result in more advantageous risk-return relationships and is explored later by examining the coefficient of variation.

### ***6.1.4. Coefficient Variation***

The coefficient of variation, Table 4, ranges from a low of 4.28 at 380/80 to extremely high levels where the average profit is near zero. The coefficient of variation decreases in an irregular manner as the opening limit increases to 320 and then rises at higher levels of the opening limit. The lowest value for the coefficient of variation occurs at opening limit levels of 320 to 380. At opening limits below 380 the minimum coefficient of variation occurs at a closing limit of zero. At opening limits of 380 and 400 the minimum shifts to a closing limit of 80. For opening limits of 280 and greater the coefficient is fairly steady over a wide range of limits suggesting a consistent risk-return relationship.

### ***6.1.5. Percentage of Profitable Trades***

The percentage of profitable trades, Table 5, ranges from 35% at 100/80 to 73% at opening limits of 380 and 400 at mostly low closing limits. The percentage increases in a fairly steady manner

as the opening limit increases and is generally greatest at or near a closing limit of zero. If the level of profit is normally distributed, which it is not, a coefficient of variation of 4.28 (the best possible combination as noted above) would signify approximately a 55% probability of gain. The fact that the probability of gain is somewhat higher (72% again at 380/80) is a result of skewness in the distribution of profit.

#### ***6.1.6. Maximum Profit and Maximum Loss***

The maximum profit is \$1,210 at all limits. This is caused by the same outlier trade in each case. The maximum loss is -\$3,089 at all closing limits of 120 or lower, -\$3,249 at all closing limits of 140 through 160, and -\$1,515 at closing limits of 180-200 combined with opening limits of 360 or less. Combinations of closing limits of 180-200 and opening limits of 380-400 result in a maximum loss of -\$1,454. All opening limits result in the same maximum loss at each closing limit level with the exception of opening limits above 360. Within the range of limits studied the closing limit controls the maximum loss.

#### ***6.1.7. Average Trade Length***

The average trade length, Table 6, ranges from 1.79 days at 220/200 to 4.34 days at 200/0. At low closing limit levels the average trade length generally increases slightly with the opening limit up to an opening limit of 200, and then generally declines slightly. However, at closing limit levels of 60 or higher the average trade length continues to increase as the opening limit increases. Higher closing limits in general tend to reduce average trade length since the trade does not need to return as far towards the recent average spread. Overall, average trade length exhibits relative stability.

#### ***6.1.8. Average Length of Profitable Trades***

The average length of profitable trades, Table 7, ranges from 1.27 days at 220/200 to 2.63 days at 220/0. The average length of profitable trades behaves much the same as the average length of

all trades; as might be expected given the high percentage of profitable trades. However, the average length of profitable trades is lower at all levels, typically by approximately 1 day. This is the first indication that profitable and unprofitable trades differ systematically in length. In general, higher closing limits reduce average profitable trade length and higher opening limits increase average profitable trade length, as least to opening limits of 220. Above opening limits of 220 the values fluctuate but are relatively stable.

#### ***6.1.9 . Average Length of Unprofitable Trades***

The average length of unprofitable trades, Table 8, ranges from 2.16 days at 220/200 to 7.74 days at 400/0. The average length of unprofitable trades is always at least 1.71 times as large as the average length of profitable trades and on average (equally weighted for all combinations of limits) is 2.58 times as large. This results in unprofitable trades being, on average, approximately 3 days longer than profitable trades. At high opening limits with low closing limits unprofitable trades are 5 days longer than profitable trades on average while at low opening limits with high closing limits unprofitable trades are only 1 day longer than profitable trades on average. At limits of 380/140, for example, the average length of unprofitable trades is significantly longer than the average length of profitable trades at .01%. The opportunity to distinguish between profitable and unprofitable trades on the basis of length, however, depends on how the two distributions overlap.

#### ***6.1.10. Maximum Trade Length***

Maximum trade length, Table 9, ranges from 13 days at various combinations of opening limits above 240 and closing limits of 180 or greater to a high of 24 for opening limits of 100 to 180 with closing limits of 40 or less. In general, low opening and closing limits produce high maximum trade lengths. Closing limits near the opening limit slightly decrease the maximum length. This suggests that high opening limits signal situations where there is intense pressure to return toward zero while low opening limits (especially very low opening limits not reported in this paper) may capture situations where the current trend is away from zero.

#### ***6.1.11. Maximum Length of Profitable Trades***

The maximum length of profitable trades, Table 10, ranges from 5 days at high opening and closing limits to 9 days at combinations of low opening and closing limits. This parameter is, of course, determined by some individual trade.

#### ***6.1.12. Minimum Length of Unprofitable Trades***

The minimum length of unprofitable trades, Table 11, ranges from 1 to 3 days. Highest values are at opening limits of 220 to 280 and closing limits of 20 or less. As with the maximum length of profitable trades, this parameter is potentially affected by some outlier trade. The obvious implication of some unprofitable trades being shorter than some profitable trades is that it may not be profitable to truncate trade length in an attempt to avoid the worst trades.

### ***6.2. Segmenting the Study***

#### ***6.2.1. Time Segment Characteristics***

Crush spread results are compiled for four equal non-overlapping time segments in Table 12. Results vary systematically over the time segments. The first segment has, on average, a negative crush spread while the mean crush spread over the remaining three segments is 1,716. Although the fourth segment has the lowest standard deviation of the spread, it has the highest kurtosis and the most positive skewness. This increased incidence of extreme changes potentially leads to incorrect buy and sell signals.

#### ***6.2.2. Trade Results by Segment***

The four time segments are analyzed for differences in trade results in Table 13. In general, the fourth time segment gives negative average profit results, a higher standard deviation of profit, a

lower percentage of profitable trades, and longer trade length. These results demonstrate that even should a profitable set of opening and closing limits be found, in general, specific time periods may yield negative results. Traders need be aware of changing spread characteristics due to heteroskedasticity. The problem during the fourth time period was that spread deviations large enough to trigger trades were sometimes followed by further movement away from the 5-day moving average. Reversal of that movement away from the average was sometimes rapid enough to trigger the closing trade based on the updated moving average, but at a price disadvantageous to the initial position.

The soybean crush spread must be evaluated in the context of worldwide production of numerous crops of varying substitution opportunity in an industry with regulation of production, price supports, and trade quotas. Soybean meal and oil are just one source of protein and oil for animal feed, human consumption, and industrial use. Corn is the typical alternative for animal feed, the overwhelming use of soy meal. Canola is a major alternative to soy oil. Changes in the supply and demand conditions, including crushing capacity, may render the crush spread unstable. Goodwin, Schnepf, and Dohlman (2005) find that the pricing relationships for soybeans change over time with major structural breaks. Kruse (2003) reports that while meal demand is highly price elastic, oil demand is more inelastic, and that the elasticities change over time. Further econometric research beyond the scope of this study is needed to better understand the changing nature of the process which determines the crush spread.

### ***6.3. Ignoring Transaction Costs***

When transaction costs are ignored, the percentage of profitable trades increases from the range of 31% - 74% to the range of 72% - 80%. Additionally, the systematic difference between the length of winning and losing trades is increased. For example, at 380/140 the percentage of profitable trades increases from 71% to 80%, while the average length of winning trades increases from 1.71 to 1.91 days, and the average length of losing trades increases from 5.17 to 6.00 days. It is interesting that BOTH the overall (un-weighted) average length of profitable trades (increases by .23 days) and the average length of losing trades (increases by 1.17 days) increase as some of the relatively short losing trades with transaction costs become relatively

longer profitable trades without transaction costs. Consistent with this, the maximum length of profitable trades increases by 1 to a length of 4 days in most events at closing limits of 100 or less. Similarly, the minimum loss length increases by 1 day at most combinations of limits.

Meanwhile, the coefficient of variation of course falls, as profit has been increased by \$103.5 while the standard deviation is unchanged. In the case of 380/140, the coefficient of variation falls from 5.22 to 2.56 when transaction costs are ignored. It is this change in coefficient of variation as a measure of the risk-return relationship which potentially creates differential arbitrage opportunities. Traders with lower transaction costs face better risk-return relationships. The transaction costs of the most efficient traders that will dictate market behavior.

#### ***6.4. Short versus Long Trades***

Results are compiled separately for short and long trades in Table 14. Long trades are more profitable on average and have a higher likelihood of profitability but have a higher standard deviation of profit. Consistent with this are higher maximum gains and losses for long trades. Some combinations of limits do have a lower coefficient of variation for long trades. Statistics for trade lengths are very similar for short and long trades.

#### ***6.5. Higher Limits***

Higher opening limits (up to 800/400) are also studied with transaction costs. The number of trades drops precipitously. While average profit fails to increase, the percentage of profitable trades hovers in the 60-70% range. Probability of gain as high as 77% exists (560/0 and 560/40), but the coefficient of variation is 5.95 and 7.24 respectively with average profit of \$142.82 and \$115.23. In general the coefficient of variation at higher opening limits deteriorates, although it is as low as 2.24 at 800/400. Unfortunately only 8 trades exist over the 20-year study period at this level and waiting for them is likely not justified by the \$242 average profit.



### **6.6. Reversal Strategy**

The strategy of reversing trades only when the spread has reached a level equal but of opposite sign to the opening limit, as employed by Simon, reduces the number of trades and increases average profit, the standard deviation of returns, and the coefficient of variation.

Table 15 (Panel A) examines the relationship between average profit, standard deviation of profit, and the coefficient of variation over a variety of closing limits. In general, profits are maximized at limits slightly beyond the 5-day moving average but short of complete reversal of sign. Opening limits of 100 are clearly not profitable at transaction costs of \$103.50 while profits are maximized at opening limits of 200, 300 and 400 at closing limits of -100, -100 and -150 respectively. Results reported by Simon are shown in Panel B of Table 15.

Some movement beyond the 5-day moving average can safely be anticipated, though not complete reversal. At the same time, the standard deviation of profit almost always increases as the closing limit moves farther from the opening limit. This implies that the risk-return relationship (as measured by the coefficient of variation) is optimized when closing trades only slightly beyond the 5-day moving average.

While the standard deviations in this study are similar to those reported by Simon, Simon experiences greater profitability over the earlier portion of the longer time period employed in this study. As earlier discussed, the fourth time segment reduces overall profitability. This again serves to emphasize the importance of a long study period and the susceptibility of trading rules to changes in market behavior. A trader who bases their trading practices on the results for \$200 limits reported by Simon would experience, over the 20-year period, average losses of \$20 per trade rather than an approximate \$200 average profit per trade as reported by Simon.

### **6.7. Summary of Analysis**

A risk-return tradeoff (coefficient of variation) indicates that contrary to the symmetric limits studied by Simon (e.g., short the crush if the spread is greater than \$100 above the 5-day moving

average and reverse the trade if the spread is \$100 less than the 5-day moving average), traders can benefit by reversing trades near the 5-day moving average. Average profit increases, the standard deviation of profit decreases, and the percentage of winning trades increases.

Traders also may benefit from establishing trade length limits (i.e., truncating trades). Losing trades are, on average, significantly longer than winning trades. Artificial trade length limits may help to reduce the incidence and severity of the worst losing trades.

### ***6.8. Truncation of Trade Length***

Because the average length of profitable trades is lower than the average length of losing trades, and because the maximum length of profitable trades is relatively short; it may be profitable to truncate trade length. For example, no trade at any set of limits up to 400/200 produces a profitable trade in excess of 9 days and almost no profitable trades over 7 days exist at opening limits over 200. See Table 10. Truncating trades may or may not avoid losing trades, and could exacerbate losses if trades are closed before a reversal (closing) signal is produced by the spread.

Three trade truncation limits are studied. In general, the coefficient of variation is improved as the trade truncation limit is reduced to 10 or 8 days. At a truncation limit of 6 days the coefficient of variation begins to increase. This is demonstrated with un-weighted averages of all coefficients of variation at opening limits of 300 and higher. The region of 300 and higher is chosen due to negative and extremely high coefficient of variations at lower opening limits which indicate unlikely opportunities for arbitrage attempts. The average coefficient of variation falls from 5.72 to 5.60 to 5.30 and then rises to 6.56 for unlimited trade length, 10-day, 8-day and 6-day limits respectively. These same trade truncation limits have minimal effect on the probability of profitable trades. The shortened trades avoid few losses and free up the trading account for additional trades in the same unfavorable environment that caused the original trade to lose money. Therefore, the trade truncation limits are judged non-beneficial.

Trade truncation if a contract roll-over occurred during the trade failed to improve results. Results for that variation are not reported here.

## **7. CONCLUSIONS AND IMPLICATIONS FOR FURTHER RESEARCH**

Unless further research demonstrates arbitrage limits (filters) with more appealing risk-return characteristics, the soybean crush spread should be considered an efficient market. Although the risk-return relationships are not consistent, they do not provide profitable arbitrage opportunities using a variety of opening and closing limits.

In contrast to previous work by Simon, profitable trades are significantly shorter than losing trades. However, truncating trade lengths in an attempt to segregate gains from losses does not significantly improve results.

The averaging period employed to determine significant deviations should be explored to ascertain if a longer (shorter) period better identifies significant deviations. Similarly, other more sophisticated arbitrage identification techniques such as Simon's "Fair Value", regression techniques, and neural networks may still yield arbitrage opportunities. In October, 1992 the CBOT changed the soybean contract specifications from 44% protein to 48% protein. A more exact representation of the spread as it is now commonly traded of 10 soybean, 9 soyoil, and 11 soybean contracts, for all contracts expirations after October, 1992, may better track prices.

The persistence of those arbitrage opportunities that do exist could also be investigated. Further research may want to examine the effects of doubling-up transactions i.e., creating second transactions on top of existing trades. It would be interesting to note how long a trader has available to exploit an arbitrage opportunity and the continued existence of such opportunities would further explore market efficiency.

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## **TABLES**

**Table 1. Number of Trades**

Rows show Opening Limits, Columns show Closing Limits

	0	20	40	60	80	100	120	140	160	180	200
100	805	846	892	935	994	-	-	-	-	-	-
120	682	711	739	769	811	844	-	-	-	-	-
140	578	598	619	642	669	694	723	-	-	-	-
160	478	490	501	518	538	554	576	592	-	-	-
180	403	412	419	431	444	455	468	482	492	-	-
200	340	349	352	362	370	379	389	395	402	411	-
220	285	292	295	301	307	316	322	326	331	336	341
240	238	243	243	248	252	258	260	263	266	271	275
260	209	211	211	214	217	221	223	226	229	232	235
280	183	185	185	187	190	192	193	195	196	199	201
300	148	149	149	151	154	154	154	156	157	160	162
320	131	132	132	134	137	137	137	139	140	142	143
340	117	118	118	119	121	121	121	123	124	126	127
360	99	99	99	100	102	102	102	103	104	105	106
380	82	82	82	83	83	83	83	84	84	85	86
400	70	70	70	71	71	71	71	72	72	73	74

Note: Both long and short trades are included. “100” represents opening limits of +100 for short trades and -100 for long trades. Closing limits are of the same sign as opening limits.

**Table 2. Average Profit (\$)**

Rows show Opening Limits, Columns show Closing Limits

	0	20	40	60	80	100	120	140	160	180	200
100	-26.28	-29.89	-35.31	-38.83	-41.88	-	-	-	-	-	-
120	-21.65	-24.43	-28.74	-32.90	-35.40	-37.53	-	-	-	-	-
140	-15.62	-19.34	-24.40	-27.72	-30.05	-31.33	33.47	-	-	-	-
160	-3.44	-8.08	-12.79	-15.39	-17.79	-20.17	-22.60	-24.38	-	-	-
180	4.98	0.20	-5.03	-7.31	-10.17	-12.07	-15.19	-16.73	-22.20	-	-
200	11.41	6.87	0.33	-1.38	-4.48	-5.13	-8.50	-9.41	-15.68	-14.03	-
220	25.88	20.66	14.95	11.72	9.68	8.60	4.13	3.65	-3.68	-3.60	-8.72
240	41.94	33.90	28.67	23.32	21.85	20.11	14.82	13.58	6.08	5.84	0.46
260	58.82	47.01	41.36	37.67	36.38	36.40	31.20	30.25	24.85	25.01	18.13
280	76.11	64.66	60.12	55.56	56.23	56.00	49.32	48.71	41.65	41.90	34.37
300	87.62	75.03	69.70	65.02	66.53	62.23	52.85	53.33	47.55	48.69	42.90
320	105.35	94.09	88.28	83.29	85.43	81.63	71.97	71.85	66.25	67.79	60.01
340	100.48	89.66	83.16	81.27	82.02	77.72	67.68	69.08	62.36	65.41	55.87
360	111.13	100.92	99.24	100.34	100.79	95.54	86.18	88.66	81.41	84.26	75.00
380	119.91	108.23	106.57	118.30	118.95	111.30	97.66	99.17	95.04	98.24	86.67
400	119.25	105.56	104.96	119.77	122.17	113.23	99.20	98.78	94.34	98.08	84.64

**Table 3. Standard Deviation of Trade Profit (\$)**

Rows show Opening Limits, Columns show Closing Limits

	0	20	40	60	80	100	120	140	160	180	200
100	264	254	246	229	219	-	-	-	-	-	-
120	280	270	263	245	236	225	-	-	-	-	-
140	299	289	282	263	255	243	238	-	-	-	-
160	312	304	300	282	274	265	259	257	-	-	-
180	327	320	316	297	291	281	277	274	268	-	-
200	342	333	330	312	306	296	292	292	286	253	-
220	360	352	348	332	326	314	311	313	306	271	267
240	384	375	374	356	351	339	338	342	336	296	290
260	399	392	391	369	365	353	352	356	352	307	301
280	419	412	411	392	386	375	376	381	378	329	323
300	452	446	446	424	416	412	415	420	416	360	351
320	474	468	468	444	435	430	433	439	436	376	369
340	499	493	493	468	459	455	457	463	460	395	388
360	528	526	526	500	489	485	488	496	492	421	413
380	556	554	554	513	509	504	508	518	520	430	420
400	595	593	592	548	543	538	542	553	553	453	442



**Table 4. Coefficient of Variation of Trade Profit**

Rows show Opening Limits, Columns show Closing Limits

	0	20	40	60	80	100	120	140	160	180	200
100	-	-	-	-	-	-	-	-	-	-	-
120	-	-	-	-	-	-	-	-	-	-	-
140	-	-	-	-	-	-	-	-	-	-	-
160	-	-	-	-	-	-	-	-	-	-	-
180	65.7	1637.	-	-	-	-	-	-	-	-	-
200	30.0	48.5	1010.	-	-	-	-	-	-	-	-
220	13.9	17.0	23.3	28.3	33.7	36.5	75.4	85.7	-	-	-
240	9.16	11.1	13.1	15.3	16.1	16.9	22.8	25.2	55.3	50.6	625.
260	6.79	8.34	9.46	9.8	10.0	9.70	11.3	11.8	14.2	12.3	16.6
280	5.50	6.37	6.84	7.06	6.87	6.71	7.63	7.83	9.09	7.85	9.39
300	5.16	5.95	6.40	6.52	6.25	6.62	7.85	7.87	8.75	7.38	8.19
320	4.50	4.98	5.30	5.33	5.09	5.27	6.01	6.10	6.57	5.54	6.14
340	4.97	5.50	5.92	5.76	5.60	5.85	6.75	6.70	7.37	6.04	6.94
360	4.75	5.21	5.30	4.98	4.85	5.07	5.66	5.59	6.04	5.00	5.50
380	4.64	5.12	5.20	4.34	4.28	4.53	5.21	5.22	5.48	4.38	4.85
400	4.99	5.62	5.64	4.57	4.45	4.75	5.46	5.60	5.87	4.62	5.23

Note: Results are not shown for cells with negative average profit.

**Table 5. Percentage of Profitable Trades**

Rows show Opening Limits, Columns show Closing Limits

	0	20	40	60	80	100	120	140	160	180	200
100	51	48	42	39	35	-	-	-	-	-	-
120	52	49	45	42	39	36	-	-	-	-	-
140	54	52	48	45	42	38	36	-	-	-	-
160	54	53	51	49	46	43	41	39	-	-	-
180	55	55	54	52	49	46	44	41	39	-	-
200	55	55	54	53	51	50	47	46	43	42	-
220	56	58	55	54	53	52	50	48	44	43	42
240	60	61	58	57	56	55	55	53	50	48	47
260	64	64	62	60	59	59	59	58	55	53	51
280	65	64	63	62	62	62	62	63	60	57	55
300	64	62	62	62	61	62	62	63	61	59	59
320	67	67	67	67	66	67	66	67	66	64	63
340	66	66	65	66	65	66	65	67	64	63	62
360	71	70	70	69	68	70	69	70	67	67	66
380	73	73	73	73	72	72	71	71	73	72	71
400	73	73	73	73	73	73	72	72	72	71	70

**Table 6. Average Trade Length (Days)**

Rows show Opening Limits, Columns show Closing Limits

	0	20	40	60	80	100	120	140	160	180	200
100	4.12	3.62	3.12	2.73	2.36	-	-	-	-	-	-
120	4.24	3.71	3.25	2.87	2.50	2.23	-	-	-	-	-
140	4.29	3.82	3.37	2.98	2.63	2.35	2.07	-	-	-	-
160	4.31	3.89	3.48	3.08	2.74	2.48	2.19	1.98	-	-	-
180	4.32	3.95	3.56	3.14	2.85	2.58	2.31	2.10	1.92	-	-
200	4.34	3.95	3.59	3.20	2.92	2.66	2.38	2.20	2.00	1.86	-
220	4.30	3.93	3.57	3.28	3.00	2.73	2.44	2.26	2.05	1.92	1.79
240	4.17	3.84	3.57	3.27	3.02	2.77	2.53	2.37	2.16	2.01	1.87
260	4.15	3.81	3.56	3.29	3.04	2.81	2.57	2.41	2.21	2.06	1.93
280	4.08	3.78	3.52	3.26	3.03	2.81	2.56	2.42	2.25	2.08	1.94
300	4.07	3.85	3.66	3.37	3.11	2.94	2.71	2.57	2.40	2.24	2.11
320	4.02	3.81	3.66	3.37	3.09	2.92	2.70	2.55	2.41	2.27	2.15
340	4.15	3.92	3.75	3.45	3.21	3.01	2.81	2.65	2.50	2.37	2.26
360	4.04	3.90	3.76	3.48	3.23	3.04	2.83	2.70	2.53	2.40	2.29
380	3.90	3.76	3.68	3.36	3.13	3.02	2.86	2.74	2.65	2.51	2.37
400	3.94	3.77	3.70	3.48	3.27	3.14	2.97	2.88	2.79	2.62	2.46

**Table 7. Average Length of Profitable Trades (Days)**

Rows show Opening Limits, Columns show Closing Limits

	0	20	40	60	80	100	120	140	160	180	200
100	2.22	2.05	1.77	1.61	1.47	-	-	-	-	-	-
120	2.30	2.10	1.85	1.69	1.54	1.44	-	-	-	-	-
140	2.35	2.15	1.90	1.73	1.57	1.47	1.37	-	-	-	-
160	2.36	2.14	1.89	1.73	1.58	1.49	1.40	1.33	-	-	-
180	2.44	2.24	1.97	1.82	1.65	1.55	1.44	1.37	1.30	-	-
200	2.50	2.28	2.02	1.84	1.65	1.55	1.46	1.38	1.31	1.29	-
220	2.61	2.38	2.12	1.96	1.76	1.64	1.53	1.46	1.36	1.33	1.27
240	2.56	2.39	2.20	2.03	1.80	1.66	1.56	1.51	1.42	1.38	1.29
260	2.63	2.39	2.22	2.08	1.82	1.67	1.59	1.54	1.46	1.41	1.32
280	2.58	2.35	2.19	2.03	1.82	1.66	1.58	1.55	1.49	1.44	1.34
300	2.54	2.34	2.24	2.08	1.83	1.67	1.60	1.57	1.50	1.45	1.37
320	2.53	2.44	2.34	2.19	1.96	1.80	1.69	1.62	1.53	1.47	1.38
340	2.56	2.45	2.36	2.23	2.04	1.86	1.75	1.67	1.58	1.53	1.42
360	2.60	2.48	2.43	2.28	2.04	1.90	1.80	1.74	1.66	1.60	1.47
380	2.57	2.47	2.42	2.28	2.08	1.95	1.83	1.77	1.74	1.66	1.51
400	2.53	2.41	2.37	2.37	2.33	2.15	1.98	1.96	1.87	1.73	1.65

**Table 8. Average Length of Unprofitable Trades (Days)**

Rows show Opening Limits, Columns show Closing Limits

	0	20	40	60	80	100	120	140	160	180	200
100	6.10	5.04	4.09	3.44	2.84	-	-	-	-	-	-
120	6.32	5.27	4.39	3.72	3.11	2.67	-	-	-	-	-
140	6.62	5.63	4.73	4.01	3.39	2.90	2.46	-	-	-	-
160	6.66	5.90	5.19	4.38	3.73	3.22	2.73	2.39	-	-	-
180	6.64	6.04	5.42	4.57	4.01	3.47	2.98	2.62	2.32	-	-
200	6.63	6.03	5.46	4.74	4.24	3.77	3.22	2.89	2.52	2.27	-
220	6.54	6.10	5.40	4.88	4.43	3.93	3.36	2.99	2.60	2.36	2.16
240	6.56	6.08	5.52	4.92	4.59	4.18	3.71	3.35	2.90	2.60	2.37
260	6.85	6.33	5.76	5.15	4.83	4.49	3.99	3.65	3.15	2.80	2.57
280	6.88	6.36	5.88	5.31	5.00	4.71	4.21	3.90	3.40	2.93	2.67
300	6.74	6.34	6.02	5.51	5.17	5.03	4.55	4.30	3.82	3.40	3.16
320	7.07	6.65	6.30	5.77	5.35	5.20	4.64	4.43	4.08	3.71	3.45
340	7.20	6.78	6.34	5.88	5.40	5.24	4.81	4.61	4.11	3.83	3.65
360	7.52	7.17	6.80	6.16	5.70	5.65	5.09	4.94	4.32	4.00	3.89
380	7.55	7.27	7.14	6.36	5.87	5.83	5.38	5.17	5.09	4.67	4.48
400	7.74	7.42	7.32	6.53	6.11	6.05	5.55	5.45	5.35	4.86	4.64

**Table 9. Maximum Trade Length (Days)**

Rows show Opening Limits, Columns show Closing Limits

	0	20	40	60	80	100	120	140	160	180	200
100	24	24	24	17	17	-	-	-	-	-	-
120	24	24	24	17	17	17	-	-	-	-	-
140	24	24	24	17	17	17	17	-	-	-	-
160	24	24	24	17	17	17	17	16	-	-	-
180	24	24	24	17	17	17	17	16	16	-	-
200	22	22	22	17	17	17	17	16	16	14	-
220	17	17	17	17	17	17	17	16	16	14	14
240	17	17	17	17	17	17	17	16	16	14	14
260	17	17	17	17	17	17	17	16	16	13	13
280	17	17	17	17	17	17	17	16	16	13	13
300	17	17	17	17	17	17	17	16	16	13	13
320	17	17	17	17	17	17	17	16	16	13	13
340	17	17	17	17	17	17	17	16	16	13	13
360	17	17	17	17	17	17	17	16	16	13	13
380	17	17	17	17	17	17	17	16	16	13	13
400	17	17	17	17	17	17	17	16	16	13	13

**Table 10. Maximum Length of Profitable Trades (Days)**

Rows show Opening Limits, Columns show Closing Limits

	0	20	40	60	80	100	120	140	160	180	200
100	9	9	7	5	5	-	-	-	-	-	-
120	7	7	7	5	5	5	-	-	-	-	-
140	7	7	7	5	5	5	5	-	-	-	-
160	7	7	6	5	5	5	5	5	-	-	-
180	7	7	5	5	5	5	5	5	5	-	-
200	6	6	5	5	5	5	5	5	5	5	-
220	6	6	5	5	5	5	5	5	5	5	5
240	6	6	5	5	5	5	5	5	5	5	5
260	7	6	5	5	5	5	5	5	5	5	5
280	7	6	5	5	5	5	5	5	5	5	5
300	7	6	5	5	5	5	5	5	5	5	5
320	6	6	5	5	5	5	5	5	5	5	5
340	5	5	5	5	5	5	5	5	5	5	5
360	5	5	5	5	5	5	5	5	5	5	5
380	5	5	5	5	5	5	5	5	5	5	5
400	5	5	5	5	5	5	5	5	5	5	5

**Table 11. Minimum Length of Unprofitable Trades (Days)**

Rows show Opening Limits, Columns show Closing Limits

	0	20	40	60	80	100	120	140	160	180	200
100	1	1	1	1	1	-	-	-	-	-	-
120	1	1	1	1	1	1	-	-	-	-	-
140	1	1	1	1	1	1	1	-	-	-	-
160	1	1	1	1	1	1	1	1	-	-	-
180	2	1	1	1	1	1	1	1	1	-	-
200	2	1	1	1	1	1	1	1	1	1	-
220	3	3	2	2	1	1	1	1	1	1	1
240	3	3	2	2	2	1	1	1	1	1	1
260	3	2	2	2	2	1	1	1	1	1	1
280	3	2	2	2	2	1	1	1	1	1	1
300	2	2	2	2	2	2	1	1	1	1	1
320	2	2	2	2	2	2	2	2	1	1	1
340	2	2	2	2	2	2	2	2	1	1	1
360	2	2	2	2	2	2	2	2	1	1	1
380	2	2	2	2	2	2	2	2	2	2	2
400	2	2	2	2	2	2	2	2	2	2	2



**Table 12. Time Segment Statistics for Crush Spread**

Segment	1	2	3	4
Begin	7/2/1984	12/4/1989	5/12/1995	10/18/2000
End	12/1/1989	5/11/1995	10/17/2000	4/7/2006
Observations	1,372	1,372	1,372	1,372
Mean	-36	1,784	1,372	1,993
Standard Deviation	801	1,066	941	736
Skewness	0.28	0.43	1.02	1.44
Kurtosis	-0.45	-0.70	0.34	6.71

**Table 13. Sample Time Segment Trade Results**

Open/Close	Segment	Number of Trades	Average Profit (\$)	Standard Deviation of Profit (\$)	Percentage Of Trades Profitable	Average Trade Length (Days)
100/0	1	231	2	277	57	4.01
100/0	2	181	-18	154	50	3.82
100/0	3	194	-13	265	49	4.28
100/0	4	199	-66	320	46	4.38
200/0	1	116	31	314	55	4.38
200/0	2	49	26	190	65	4.00
200/0	3	85	74	335	60	4.20
200/0	4	90	-71	425	44	4.62
300/0	1	63	102	336	65	4.13
300/0	2	13	39	191	62	4.15
300/0	3	41	239	386	66	3.41
300/0	4	31	-98	693	58	4.81
400/0	1	30	112	379	70	4.33
400/0	2	5	83	220	81	3.60
400/0	3	21	403	401	64	2.19
400/0	4	14	-278	996	73	5.86

**Table 14. Short versus Long Trade Results**

Characteristic	Short	Long
Average Number of trades	140	142
Average Profit	\$23.87	\$54.30
Average Standard Deviation of Profit	\$345	\$413
Minimum Coefficient of Variation	4.16 at 380/60	3.15 at 400/180
Largest Gain	\$952	\$1,210
Largest Loss	-\$2,293	-\$3,249
Average Maximum Trade Length / Actual	15.26 / 26 Days	15.64 / 18 Days
Average Percentage of Profitable Trades	54%	62%
Max Profitable Trade Length (Average / Max.)	5.21 / 9 Days	4.70 / 7 Days
Min Unprofitable Trade Length (Average / Min.)	1.57 / 1 Days	1.74 / 1 Days
Average Profitable Trade Length	1.83 Days	1.89 Days
Average Unprofitable Trade Length	4.88 Days	4.73 Days

Note: Results in Table 14 include the same opening and closing limits reported in Tables 1-11.

**Table 15. Reversal Strategy**

**Panel A: Sample Time Segment Trade Results**

Rows show Opening Limits and Columns show Closing Limits

Average Profit													
	200	150	100	50	0	-50	-100	-150	-200	-250	-300	-350	-400
100				-38	-26	-18	-11						
200		-9	-5	0	11	17	20	-2	-20				
300	43	54	63	72	88	107	110	104	63	48	143		
400	85	101	114	111	119	139	171	195	148	100	162	89	80
Standard Deviation of Profit													
	200	150	100	50	0	-50	-100	-150	-200	-250	-300	-350	-400
100				241	265	300	357						
200		289	296	329	342	360	401	517	604				
300	351	416	412	443	452	458	475	556	634	814	1080		
400	442	553	538	590	595	599	609	617	675	855	1099	1269	1393
Coefficient of Variation													
	200	150	100	50	0	-50	-100	-150	-200	-250	-300	-350	-400
100				Neg	Neg	Neg	Neg						
200		Neg	Neg	Undef	30.0	20.6	20.1	Neg	Neg				
300	8.16	7.70	6.54	6.15	5.16	4.28	4.34	5.36	10.0	17.1	7.55		
400	5.20	5.48	4.72	5.32	4.99	4.32	3.57	3.17	4.56	8.56	6.80	14.2	17.3

**Panel B: Results Reported by Simon**

Opening Limit	Closing Limit	Average Profit	Standard Deviation	Coefficient of Variation
Long Trades				
-100	+100	\$27	\$406	15.04
-200	+200	\$231	\$569	2.46
-300	+300	\$355	\$1,092	3.08
Short Trades				
+100	-100	\$33	\$284	8.61
+200	-200	\$185	\$362	1.96
+300	-300	\$185	\$549	2.97