Test of the Overreaction Theory of Price Limits in Futures Markets

Yongzhong Zhu

A Thesis
In
The John Molson School of Business

Presented in Partial Fulfillment of the Requirements
for the Degree of Master of Science in Administration (Finance) at
Concordia University
Montreal, Quebec, Canada

May 2006

Library and
Archives Canada

Published Heritage
Branch

395 Wellington Street
Ottawa ON K1A 0N4
Canada

Bibliothèque et
Archives Canada

Direction du
Patrimoine de l'édition

395, rue Wellington
Ottawa ON K1A 0N4
Canada

Your file Votre référence
ISBN: 978-0-494-34611-2
Our file Notre référence
ISBN: 978-0-494-34611-2

NOTICE:
The author has granted a non-exclusive license allowing Library and Archives Canada to reproduce, publish, archive, preserve, conserve, communicate to the public by telecommunication or on the Internet, loan, distribute and sell theses worldwide, for commercial or non-commercial purposes, in microform, paper, electronic and/or any other formats.

The author retains copyright ownership and moral rights in this thesis. Neither the thesis nor substantial extracts from it may be printed or otherwise reproduced without the author's permission.

AVIS:
L'auteur a accordé une licence non exclusive permettant à la Bibliothèque et Archives Canada de reproduire, publier, archiver, sauvegarder, conserver, transmettre au public par télécommunication ou par l'Internet, prêter, distribuer et vendre des thèses partout dans le monde, à des fins commerciales ou autres, sur support microforme, papier, électronique et/ou autres formats.

L'auteur conserve la propriété du droit d'auteur et des droits moraux qui protège cette thèse. Ni la thèse ni des extraits substantiels de celle-ci ne doivent être imprimés ou autrement reproduits sans son autorisation.

In compliance with the Canadian Privacy Act some supporting forms may have been removed from this thesis.

While these forms may be included in the document page count, their removal does not represent any loss of content from the thesis.

Conformément à la loi canadienne sur la protection de la vie privée, quelques formulaires secondaires ont été enlevés de cette thèse.

Bien que ces formulaires aient inclus dans la pagination, il n'y aura aucun contenu manquant.

Canada

ABSTRACT

Test of the Overreaction Theory of Price Limits in Futures Markets

Yongzhong Zhu

In this thesis we examine the effects of daily price limits on futures trading and test the overreaction theory of price limits in futures markets. The overreaction theory states that price limits can be used to correct the overreaction in the market and then reduce the excess volatility. This thesis studies both corn and soybean futures on the Chicago Board of Trade during a twelve year period from July 1, 1982, to November 30, 2004, and conducts tests to see if the futures price volatility is reduced during the day or days after limit hits in futures markets.

We use event study methodology to compare matched samples. Our tests find little evidence supporting the overreaction theory. On the contrary, our results show strong spillover effects and provide strong evidence indicating that price limits mainly suspend the transaction and delay the price discovery and make the market less efficient, especially when the price limit level is set too narrow.

Further tests indicate that the overreaction theory may work at an intra-day level. The overreaction built up is reduced during the first several minutes after a price limit is hit. Results also show that overreaction is just a minor effect and the overreaction theory only depicts a small part of the picture of how price limits work.

We propose that in most situations where the optimized limit level is unknown, we should set limit levels wider rather than narrower, to avoid delayed transactions and inefficient market prices.

DEDICATION

This thesis is dedicated to my mother, Wanqiong Cao, who has just passed into another world or whatever place you choose to believe, with love and thanks for all she has done for me throughout my life.

ACKNOWLEDGEMENTS

I thank my supervisor, Dr. Latha Shanker, for the patient guidance and constant encouragement that she provided, from the inception of this thesis.

I thank Dr. Greg Lypny and Dr. Thomas Walker for helpful comments.

I also thank my father, Xinyuan Zhu, and my brother, Hengzhong Zhu, for their love and support always.

LIST OF CONTENTS

LIST OF TABLES

1. Introduction

Futures contracts are traded on organized exchanges. Trading of these contracts is distinguished by two features: 1) the daily settlement rule, under which the profits or losses incurred by open positions in the contract are settled daily; and 2) daily price limits, which limit the range of futures prices in a trading day. In this thesis, we examine the effects of daily price limits on futures trading and test the overreaction theory of price limits in futures markets.

The overreaction theory states that investors tend to overreact to news in a financial market, which implies that if positive news enter a futures market, the futures price will rise to a higher level than it should and if negative news enter the market, the futures price will fall to a lower level than it should. As a theory of price limits, the overreaction theory also states that price limits can correct this mispriced effect and keep the price at its equilibrium level, which also means that price volatility can be reduced by limit hit occurrences.

This thesis conducts tests to examine whether the futures price volatility is reduced during the day or days after limit hits in futures markets. My sample covers both corn and soybean futures traded on the Chicago Board of Trade during a twelve year period from July 1, 1982, to November 30, 2004. As a limit hit is a rare occurrence, we choose corn and soybean futures because they are more volatile than other futures contracts and have relatively more limit hit occurrences.

We use event study methodology to compare matched samples, where the event studied is a price limit hit. That is to say, we compare the price volatility of the samples with limit hits to those samples without limit hits. Most of the tests conducted by previous researchers show results that are not consistent with the overreaction theory. Results show strong spillover effects and indicate that price limits mainly suspend the transaction, delay the price discovery and make the market less efficient, especially when the price limit level is set too narrow.

Further tests indicate that overreaction theory may work at an intra-day level. The overreaction built up is reduced during the first several minutes after a price limit is hit. The results also show that overreaction is just a minor effect and the overreaction theory only depicts a small part of the picture of how price limit works.

There are debates between price limit advocates and opponents as to whether price limits are advantageous or not. Opponents argue that the disadvantages outweigh the benefits and call for price limits to be removed. This thesis adds new insights to these debates. We are for price limits; but we believe that setting limit levels properly is also an important issue. Ideally the price limit level should be narrow enough to correct overreaction and reduce excess volatility, yet wide enough to avoid suspending and delaying transactions.

2. Literature Review

Daily price limits prevent traders from buying contracts at a price above the daily upper price limit or selling contracts at a price below the lower price limit. Several theories regarding price limits have been developed. For example, Telser (1981) argues that price limits merely delay equilibrium prices from prevailing in the market and that such a delay will not lower the default risk of the positions of individual traders. However, Brennan (1986) presents a substitution theory. According to this theory, the true price is unobservable when price limits prevent trading from taking place, which in turn creates a problem for the losing party in projecting his true losses. As a losing party is not sure of his true losses, he may have fewer incentives to default. In this way, we can expect a reduction in anticipated default rates, which could allow futures exchanges to lower margin requirements. In this sense, price limits can substitute for a higher margin level. The third theory is the so-called implementation risk theory. Kodres and O'Brien (1994) propose that price limits can enhance the total welfare of traders by transferring risk between different groups of traders in the market.

Some theories, such as that of Brennan, assume that investors are rational. However, advances in behavioral finance tell us that the real behavior of investors often contradicts rational decision-making. Harrington (2003) reviews the studies of the four pioneers in the field of behavioral finance: Smith (who pioneered the use of laboratory experiments in evaluating markets in 1956), Shiller (1978, 2000), Thaler (1976, 1996) and Shefrin (1978, 1999) whose studies all provide examples and evidence of people's irrational behavior.

Just as the numerous studies on behavioral finance suggest, human behavior displays systematic biases and associated with the somewhat irrational investors are irrational price movements. Overreaction is an example of such behavior. De Bondt and Thaler (1985, 1990) define overreaction as traders systematically over-adjusting their posterior beliefs to news by more than what is warranted by the news in the short run of a day or two. According to Daniel, Hirshleifer, and Subrahmanyam (1998), overconfident investors overestimate the precision of their private information, which causes the stock price to overreact. This means that if positive news enter the market, the price will rise to a higher level than it should and if negative news enter the market, the price will fall to a lower level than it should. They also find that, in the presence of investors' overconfidence and biased self-attribution (which means investors tend to attribute the price changes to the reasons they believe are accurate, even though they are wrong), security price changes tend to be greater than they should be in the short-term and will reverse in the long-term, thereby causing excess volatility. Evidence from cognitive psychology also shows that individuals tend to overreact to information (Kahneman and Tversky, 1981).

Although overreaction exists, price limit advocates believe that price limits can be used to prevent and correct it. Irrational investors may behave differently when a price limit is hit. For example, investors may cool off gradually after the limit is hit and become more rational than before the limit hit. In this way, price limits can reduce irrational price movements and maintain market efficiency. This is the so-called overreaction theory proposed by Anderson (1984), Khoury and Jones (1984) and Ma et al. (1989). Hieronymus (1971) indicates that the purpose of daily limits is to prevent a major price change from being carried too far by its own momentum. Anderson (1984) also argues that "most futures markets impose daily price limits ... to prevent excessive price swings". To sum up, price limits exist to prevent large movements in prices due to panic and speculation. When investors overreact, prices will exhibit excess volatility. Thus, if we find that price limits reduce price volatility, we find evidence in support of the overreaction theory.

Chou, Lin and Yu (2000) provide theoretical results which support the delayed price discovery hypothesis rather than the overreaction theory. Their results show that because of the left-over adjustment, the volatility of observed prices will be higher after a limit hit. However, previous empirical evidence on the overreaction hypothesis in futures markets is mixed. Ma et al. (1989) present evidence of overreaction in some futures markets. In contrast, Gay et al. (1994) find little evidence of overreaction but rather of delayed reaction-price dependence (which means that it takes time for the price to reflect the reaction). Chen's (1998) study indicates that overreaction is just an occasional occurrence and the market is relatively efficient in processing information, which does not support the overreaction hypothesis.

Similar studies on price limits have been conducted using stock market data. Although Kim and Rhee (1997) test three hypotheses regarding price limits (the volatility spillover hypothesis, the delayed price discovery hypothesis, and the trading interference hypothesis), they find no conclusive support for any. Yet, Lin and Chou (2002) find that, by lengthening the momentum phase (which is the period that the momentum lasts), price limits are effective in attenuating overreaction and reducing excessive volatility. Specifically, by not allowing prices to move beyond a certain range, price limits discourage overconfidence and prevent prices from departing too far from their fundamental values. That is to say, price limits can decrease price volatility and counter overreaction.

When we compare the studies of price limits in futures markets with those in stock markets, we find some differences, although both use event study methodology. For example, Kim and Rhee use an event period of 10 days while Chen uses an event period of only one day. The proxy for overreaction used is also different. Some studies use price changes while others use volatility changes. The objective of our study is to research the overreaction hypothesis in futures markets, by extending the methodology used in studies of the overreaction hypothesis in stock markets.

We employ event study methodology, but examine an event window that is wider than that used by Chen (1998). We also use different proxies for overreaction other than price changes, such as volatility changes, to determine whether or not the overreaction theory of price limits is supported.

3. Hypotheses

The null hypothesis is that price limits do not affect the observed price volatility of futures contracts. The price limits simply suspend transactions and delay discovery of the equilibrium price. This suggests that the observed price volatilities are not reduced in the day or days after a limit hit day.

In this thesis we extend Kim and Rhee's methodology to the futures market. We compare the observed price volatility of the day or days following a limit hit with the observed price volatility of the day or days following a day with a price move which does not reach the limit. Then the null hypothesis is represented by:

$$Ho: E\ (V^*|\ |\Delta\ P^*|\geq L) = E\ (V|\ |\Delta\ P|<L)$$

Where V* is the observed price volatility on the day or days following a limit hit, P* is the price on a limit hit day, V is the observed price volatility on the day or days following a day with a price move ΔP which does not reach the limit. L is the limit move.

However, according to the overreaction theory, price limits can be used to prevent short-term overreaction and reduce excess volatility. Thus, what we actually expect from the tests is that the volatility during the day or days after a limit hit day is reduced:

$$Ha: E(V^*|\,|\Delta P^*| \geq L) < E(V|\,|\Delta P| < L)$$

4. Data

We obtain data from the Futures Industry Institute (FII). We follow Chen's (2002) rule in selecting contracts. The selection procedure can be explained as follows: For each commodity, three types of contracts are traded simultaneously on many trading days. They are (i) expiring contracts, (ii) nearby contracts defined as the nearest to expiration other than the expiring contracts, and (iii) more distant contracts. Because expiring contracts may not have price limits, and trading activity on nearby contracts is typically higher than on more distant contracts, we will collect prices for nearby contracts and use them in the study.

As this is a test of a theory regarding price limits and a limit move is usually a rare occurrence, we need to find markets that experience a significant number of limit moves. Following Ma et al., we will focus on the corn and the soybeans futures contracts of the Chicago Board of Trade (CBOT). The data set contains daily open, high, low, and closing prices. When daily settlement prices are not available we replace them by daily closing prices since the two are the same on most trading days. The intraday tick price data are also necessary for the tests proposed below.

We obtain data for both corn and soybean futures for the period July 1, 1982, to November 30, 2004, as well as data on historical daily price limits from the Chicago Board of Trade. Data on all nearby contracts during the period are rolled over to a continuous data file. For tests using the time window t=[-5, 5], which means five trading days before to five days after a limit hit day, we exclude occurrences within the last five days and the first six days of each nearby contract. For other tests using daily occurrences, since some volatility estimates use both the price of the day in consideration and the previous day to calculate volatility, we exclude the first day from each nearby contract.

We identify limit hit days using the following criteria:

|previous closing price + limit – high price|≤ 2-quarter cents upper limit-hit

|previous closing price – limit – low price|≤ 2-quarter cents lower limit-hit

Then we examine intra-day tick data to confirm that a limit hit actually occurred on these days by graphing the tick data.

Let's have a look at the historical limit levels for corn and soybean contracts. The historical limit levels and number of limit hit days during each period are reported in table 1a. For corn, the limit is 10 cents/bushel from July 1982 to July 1993; then the limit changes to 12 cents/bushel, until August 1999; and finally changes to 20 cents/bushel, until the end of our sample period in November 2004. Before September 1999 (September 2000 for soybean contracts), the limit levels may expand from these levels on several days but they revert back quickly within one or two days. There are only 2 limit hit occurrences (out of 167) after August 1999 when the limit level is increased to 20 cents/bushel. For soybean contracts, the limit level is 30 cents/bushel for the period from July 1982 to August 2000 and 50 cents/bushel after that period. During the period from August 2000 to November 2004 when the limit level is 50 cents/bushel, there are only 8 limit hit occurrences (out of 128) which are concentrated in the three month period from May 2004 to July 2004.

The numbers of limit hit days for each year are reported in table 1b. From table 1a and table 1b we can see that, generally speaking, the number of limit hit days declines as the limit levels increase.

Table 1c provides summary statistics for corn and soybean futures. For each year, the average closing price and the standard deviation of closing price are reported.

5. Methodology

We will use event study methodology for most of our tests, where the event studied is a price limit hit. We use matched samples for our study. Following Kim and Rhee, we compare two samples: one without limit hits which will serve as a benchmark and the other with limit hits. They are matched on other characteristics, such as closing% (which is the ratio of the closing price P_c (normalized by subtracting the previous closing price) over the limit price L, i.e. closing% = P_c/L) and Nlimit/Ntotal (minutes when trading is constrained by the price limit over the total minutes of the trading day) as closely as possible. Our study focuses on comparing the price volatility in different event windows and on examining the differences. Event windows are defined as t = [–N_1...0...N_2]. N_1 could be set to any number ranging from 0 to 5, while N_2 could be set as 1 to see the immediate effect or 5 to include any possible spillover effects. The latter would imply that the volatility constrained by price limits in one day spills over to one or several days after a limit hit day and makes the volatility in those days larger.

5.1. Measurement of variables

Price volatility

Traditionally we calculate the standard deviation of return σ to measure the price volatility, which is a widely accepted method. However, the standard deviation can only be calculated during a period of time. As there is a need to estimate the daily price volatility and compare it day by day, and most publicly available data are daily data, some volatility estimates using daily high, low, open and closing prices have been developed. We use both the traditional standard deviation estimate and daily estimates in this thesis.

Throughout the literature on price limits there are four widely referred daily price volatility estimates: 1) classical volatility estimate, Garman and Klass (1980), Wiggins (1992), Chen (2002) all mentioned this estimate based on daily closing price in their papers, 2) Parkinson's (1980) estimate based on daily high and low prices, 3) Garman and Klass's (1980) estimate of volatility, and 4) Kim and Rhee's estimate of volatility.

The four estimates of price volatility that we use are as follows:

i. A classical volatility estimate based on daily closing prices $\sigma^2 = (C_t - C_{t-1})^2$ where C_t is the daily closing price on day t and C_{t-1} is the previous day's closing price.

ii. Parkinson's (1980) estimate based on daily high and low prices $\sigma^2 = (u-d)^2/(4\log_e 2)$ where u and d are the daily high and low prices, respectively, normalized by subtracting the open price of the same day. However, there is a downward bias if the price stays at the limit price for almost the whole day. The daily high and low price may be the same and the volatility will be zero or very close to it.

iii. Garman and Klass's (1980) estimate of volatility, which is $\sigma^2 = 0.511(u-d)^2 - 0.019(c(u+d)-2ud) - 0.383c^2$ where c is the daily closing price, normalized by subtracting the open price of the same day. For those days with prices locked at the price limit for almost the whole day, a similar downward bias exists here as that in Parkinson's estimate discussed above.

iv. Kim and Rhee's estimate of volatility, which is $\sigma^2 = R_t^2$ where, R_t represents the close-to-close returns using the closing prices on day t and day t-1.

We use multiple price volatility estimates because previous empirical studies of both stock markets and futures markets suggest that the results are sensitive to the volatility estimate used. By using different estimates of volatility we can determine if our results are robust across different volatility estimation methods.

5.2. Tests conducted

Following Kim and Rhee, we use a Wilcoxon Signed-Rank test for most of our univariate comparisons. Specifically, we use a Wilcoxon Signed-Rank test to compare the volatilities of two different samples during a given period. Shaw et al. (2000) propose the use of Wilcoxon Signed-Rank tests to test for median difference in paired data. The test statistic is based on the magnitude of the difference between pairs of observations. We pair matched occurrences and form matched samples in the tests below, calculate the difference for each paired occurrence, rank the differences by their absolute values, sum the ranks of positive and negative differences and calculate the test statistic as the lesser of these two sums. The larger the difference of the two sums, the more likely it is that the null hypothesis will be rejected. The most important advantage of the Wilcoxon Signed-Rank test is that it protects against some violations of the assumptions of parametric tests, such as normality, which means the results will still hold even if the observations are not normally distributed. In test 5 we conduct both t-tests and Wilcoxon Signed-Rank tests. The results of these two tests are consistent with each other.

We conduct the following tests using daily estimates:

- Test 1: test 1 consists of two relevant tests which are test 1a and test 1b. Chen shows that there is a 60% chance that trading will come to a complete halt for the rest of the session after limit prices are first hit. For test 1a we collect all observations in which the price rebounds from the limit price and trading resumes to form a rebound sample R. After that, according to the closing% value (which is the ratio of the closing price Pc (normalized by subtracting the previous closing price) over the limit price L, i.e. closing% = $(P_c/L) = (C_t - C_{t-1})/L$), we find the matches of the rebound observations to form the benchmark sample N. According to the overreaction theory, since the rebound sample R has hit the limit and the overreaction has been corrected or partially corrected, we can expect less volatility when compared with the benchmark sample N, which still has overreaction embedded in it. Sample R and sample N are matched by the closing% value on a limit hit day (t=0) to ensure that contracts in the two samples are the same distance away from the price limit so that they have the same starting point for the period starting from the day after a limit hit and that the two samples are comparable. We choose the time period as: t= [-5, 5] to compare volatility changes of the two samples day by day from 5 days before a limit hit to 5 days after the limit hit. We can see the immediate difference at t=1; or t= [0, 5] to include any possible spillover effects.

  For test 1b: We also collect the occurrences whose absolute closing% value is larger than 85% for soybean futures (we use 80% for corn futures, since not enough matches are found when we use 85%) from the rebound sample R and its benchmark sample N in test 1 and form sample R85 and its benchmark sample N85 (R80 and N80 for corn futures). Compared with other occurrences which have a lower closing% value, the two new samples represent occurrences which are more volatile and may have more overreaction embedded in them, if there is any. Thus, if the overreaction is corrected, the changes will be more obvious.

- Test 2: test 2 consists of four similar tests which are test 2a, test 2b, test 2c and test 2d. Following Evans and Mahoney (1997), we collect all the occurrences of limit hits and form several samples according to the fraction of the trading day in the limit, i.e. Nlimit/Ntotal, which is defined as the number of minutes trading in the futures contract is constrained by its limit price (Nlimit) over the total minutes of the trading day (Ntotal). Then we compare the price volatility among these samples. We expect that a sample with a smaller Nlimit/Ntotal ratio (less constrained) will have a larger volatility and that a sample with a larger Nlimit/Ntotal ratio (more constrained) will exhibit a smaller volatility. The rationale behind this test is that the longer the price stays at the limit price, the more the overreaction is corrected, and the less volatility should be detected; investors may cool off gradually after the limit is hit and they may have time to consult with their consultants, then make more rational decisions.

  Sample5 whose Nlimit/Ntotal $\leq$ 5% and sample96 whose Nlimit/Ntotal $\geq$ 96% are compared in test 2a for corn futures and so are sample7 (Nlimit/Ntotal $\leq$ 7%) and sample97 (Nlimit/Ntotal $\geq$ 97%) for soybean futures. We choose 5%

and 96% for corn and 7% and 97% for soybean so that the samples under comparison have the same number of occurrences. Sample0 (Nlimit/Ntotal ~ 0%) and sample100 (Nlimit/Ntotal ~ 100%) are compared in test 2b for both corn and soybean futures. Sample0 (sample5 and sample7) represents occurrences which are least constrained by price limits while sample100 (sample96 and sample97) represents the most constrained. If the overreaction theory holds, the overreaction embedded in sample100 (sample96 and sample97) might be corrected or partially corrected and the volatility will be lower than that of the benchmark sample0 (sample5 and sample7).

Test 2c and test 2d are based on the same rationale discussed above. In test 2c we divide all limit hit occurrences into halves to form two samples with the same number of occurrences. The daily volatility of Sample S (which contains occurrences which have smaller Nlimit/Ntotal ratios) and Sample L (which contains occurrences which have larger Nlimit/Ntotal ratios) are compared from 5 days before a limit hit to 5 days after the limit hit for both corn and soybean futures. Test 2d extends this approach and classifies all limit hit occurrences into three sub-samples. Sample SS (which contains the first one-third of the occurrences which have smaller Nlimit/Ntotal) and Sample LL (which contains the last one-third of the occurrences which have larger Nlimit/Ntotal) are compared with the benchmark Sample M (which contains the second one-third of the occurrences which have medium Nlimit/Ntotal) from 5 days before a limit hit to 5 days after the limit hit for both corn and soybean futures. If the overreaction theory holds, we expect volatility to be lower for Sample L and Sample LL than for Sample S and Sample SS.

- Test 3: test 3a and test 3b compare the most volatile non limit hit occurrences with those occurrences for which the closing price is locked at the limit price. We collect the occurrences for which the closing prices are locked at the upper limit to form Uplock sample U for corn futures and occurrences for which the closing prices are locked at the lower limit to form Downlock sample D for soybean futures. Sample U is compared with its benchmark sample N(+80) (which has no limit hit and closing%≥80%) for corn futures in test 3a. Similarly, sample D is compared with its benchmark sample N(-85) (which has no limit hit and closing%≤-85%) for soybean futures in test 3b. We choose 80% for corn futures and -85% for soybean contracts to create samples that have the same number of occurrences as sample U for corn and sample D for soybean contracts. According to the overreaction theory, the difference between sample U and sample N(+80) (sample D and sample N(-85) for soybeans) is that the overreaction in sample U (sample D) is corrected or partially corrected while the overreaction in sample N(+80) (sample N(-85)) is not. Thus, we can expect the volatility tol be lower for sample U (and sample D) than for sample N(+80) (and sample N(-85)). There is also a bias that sample N(+80) (and sample N(-85)) may have less volatility as they are not volatile enough to reach the price limit. Thus, if we find that the whole period volatility of sample U (sample D) is less than that of sample N(+80) (sample N(-85)), then this implies that price limits can reduce the volatility and further supports the overreaction hypothesis. Test 3a is not conducted for soybean futures and test 3b is not conducted for corn futures since not enough occurrences are found to form the test samples.

We also conduct a test using the traditional standard deviation estimate as follows:

- Test 4: Repeat all tests above using daily data to calculate the standard deviation of return σ during the period t= [-5, -1], [-4, -1], [-3, -1] which means 5, 4, 3 days before the limit hit day (t=0), and the period t= [1, 3], [1, 4], [1, 5] which means 3, 4, 5 days after the limit hit day. We compare the volatility changes for all the samples in test 1, 2, 3, 4 with their benchmark samples to see if the results are consistent.
- Test 5: In this test we still use the four daily volatility estimates used in test 1, test 2 and test 3. We calculate daily volatility using the four estimates, then set up four sets as follows:

  Set 1: all days in which neither the day itself nor the previous day are limit hit days.

  Set 2: all days which are limit hit days.

  Set 3: all days in which the previous day was a limit hit day but the day itself is not a limit hit day.

  Set 4: all days before a limit hit when the previous day was not a limit hit.

In this way, set 1 represents the average non-limit-hit day, set 2 the average limit-hit day, set 3 the average day after a limit hit, and set 4 the average day before a limit hit. All daily data during the period under consideration are included in one of the four sets.

In this test we use both parametric and non-parametric tests. In tests 5a and 5c we assume that the observations follow a normal distribution and use a t-test to compare the volatility among the four sets. In tests 5b and 5d we conduct the same comparison using the Wilcoxon Signed-Rank test as we did in earlier tests. According to the overreaction theory, price limits can correct overreaction and reduce excess volatility. We conduct this test to see whether we can find some evidence consistent with the theory by comparing volatility among the four sets, especially between set 3 and set 4 which represent the average day after a limit hit and the average day before a limit hit.

- Test 6: In our earlier tests 2c and 2d, we divided limit hit occurrences into 2 and 3 categories according to the Nlimit/Ntotal value. In this test we expand tests 2c and 2d and divide all limit hit occurrences into 12 sets for corn (8 sets for soybean) so that all sets have the same number of limit hit occurrences. For corn, Set (1/12) is the least constrained set and has the smallest Nlimit/Ntotal value while set (12/12) is the most constrained one and has the largest Nlimit/Ntotal value. (with the same sorting in set (1/8) and (8/8) for soybean contracts). By comparing volatilities between adjacent categories (set (n/12) and set ((n-1)/12) for corn futures and set (n/8) and set ((n-1)/8) for soybean contracts) during 1, 2 and 3 days after a limit hit, we gain additional insights into how price limits work.

6. Results

Results for tests 1 through 4 are reported in tables 2 to 5.

The null hypothesis that price limits do not affect price volatility is not rejected in test 1. In table 2a, we provide results for test 1a. For test 1a, none of the tests on the different estimates of volatility indicates that the volatility of the rebound sample R is less than that of the benchmark sample N after a limit hit day as the overreaction theory predicts. Just the opposite, all estimates indicate that the rebound sample R exhibits significantly larger volatility before a limit hit day which continues to be significantly larger than that of the benchmark sample N after a limit hit for corn futures. For soybean futures, except for the classical estimate on the limit hit day only, none of the estimates indicates a significant difference between the two samples N and R through the whole eleven-day period.

Table 2b provides results for test 1b. As we noted earlier, compared with test 1a, test 1b captures the most volatile occurrences for which |closing%|≥80% for corn and |closing%|≥85% for soybean contracts. Test 1b should be better suited to find a volatility reduction than test 1a if the overreaction theory holds. However, for corn, only the classical and Kim & Rhee's estimate on day 3 (on day 1 for soybeans) indicate a significant difference in volatility in the opposite direction from that which the overreaction theory predicts. All other volatilities are not significantly different for the two samples R and N.

The null hypothesis that price limits do not affect the price volatility is not rejected in test 2 either. Table 3a shows the results for test 2a. In test 2a, the samples which are most constrained by price limits (Sample96 for corn and Sample97 for soybeans) still do not exhibit significantly less volatility after a limit hit day (as the overreaction theory predicts) when compared with their benchmark (Sample5 for corn and Sample7 for soybeans) which are the least constrained. On the contrary, statistics indicate some spillover effect on day 1. Test 2b compares the extremely constrained Sample100 and its benchmark Sample0 and provides similar results. In the results for test 2a and test 2b, Parkinson and Garman & Klass estimates indicate significantly less volatility for Sample96, Sample97 and sample100 on a limit hit day (t=0) when compared with their benchmarks. This is due to the downward bias in these two estimates themselves; as for those occurrences whose Nlimit/Ntotal ratio is close to 100% in these two tests, the daily high and low price may be the same, causing the volatility estimate to be zero or very close to it.

Tests 2c and 2d also provide evidence against the overreaction theory. Table 3c and table 3d show the results for test 2c and test 2d, respectively. Almost none of the tests on the different estimates of volatility following a limit hit day suggest significant differences in the direction that the overreaction theory would predict and the null hypothesis is still not rejected. In contrast, soybean futures exhibit some spillover effect and for corn futures the spillover effect is rather strong, until five days after the limit hit day. Also, on a limit hit day (t=0), Parkinson and Garman & Klass estimates indicate significantly less volatility for the most constrained samples L and LL. Most likely this is due to the same downward bias discussed above, as many occurrences in sample L and sample LL have Nlimit/Ntotal values close to 100% which means that their daily high and low prices are the same.

In test 3 the null hypothesis is not rejected either. Results of test 3 are reported in table 4a and table 4b. For corn futures, the results suggest no significant difference between the volatility of sample N(+80) and its benchmark sample U after a limit hit day. For soybean futures, the classical estimate and Kim & Rhee's estimate suggest some spillover effect on day 1 and day 2 for sample D and its benchmark sample N(-85). However, as there is a bias that sample N(+80) and sample N(-85) may have less volatility compared with their benchmark samples U and D at the beginning, the results reported in table 4a and table 4b can not be used as evidence against the overreaction theory. As the preset bias is unfavorable to the overreaction hypothesis, we can only conclude that we do not find evidence supporting the overreaction theory with this test.

In test 4 we use the traditional standard deviation estimate to calculate the volatility during the period 5, 4, and 3 days before the limit hit day (t=0), and the period 3, 4, and 5 days after the limit hit day. Table 5 shows the results of test 4. Still none of the statistics indicate significant less volatility for samples with a limit hit when compared with their benchmark samples with no limit hit; or for more constrained samples when compared with their benchmark samples which are less constrained. There is still some spillover effect for both soybean and corn futures.

Results of test 5 also do not support the overreaction theory. Table 6a and table 6c show the parametric t-test results for tests 5a and 5c. Table 6b and table 6d provide results for the non-parametric Wilcoxon Signed-Rank test used in tests 5b and 5d. Both parametric and non-parametric tests exhibit the same pattern for both corn futures and soybean futures with all four estimates. Not surprisingly, both set 3 and set 4 exhibit significant larger daily volatility than set 1, which means the volatility of the average non-limit-hit day is significantly less than that of the day either right before a limit hit or right after a limit hit. This makes sense as we know that, on average, the days around limit hits should have larger volatility than days in non-limit-hit periods. The average limit hit day in set 2 exhibits the largest average volatility, which is significantly larger than that of the other three sets. This also makes sense. However, different from what the overreaction theory predicts, the volatility of the average after-limit-hit days in set 3 is still significantly larger than that of the average before limit hit days in set 4. This suggests that the volatility is not successfully reduced after the limit hit day. It spills over, just as the delayed price discovery hypothesis predicts.

In tables 7a and 7b we see some interesting results for test 6. When the category number is small, we only see a spillover effect as we did in tests 2c and 2d. The more constrained category (higher Nlimit/Ntotal) shows significant larger volatility than the less constrained category (lower Nlimit/Ntotal) after a limit hit day. However, as the category number increases, we start to see some evidence consistent with the overreaction theory: the more constrained category (higher Nlimit/Ntotal) shows significant less volatility than the less constrained category (lower Nlimit/Ntotal) after a limit hit day, which means price limits reduce volatility significantly. Specifically, for corn, set (5/12) which is more constrained, shows significant less volatility than set (4/12) which is less constrained; for soybean, set (4/12) shows less volatility than set (3/12). Interestingly, almost all other sets continue to show spillover effects.

The results of the tests using the four daily estimates of volatility are generally consistent. The results of the test using the traditional standard deviation estimate are consistent with the results of the tests using the daily estimates of volatility. Also, in test 5 the parametric test and non-parametric test give consistent results.

However, except for test 3 and test 5, the results for corn futures exhibit a different pattern when compared with the results for soybean, which is, the tests on the different estimates of volatility detect much stronger spillover effects for corn futures than for soybean. We believe the difference indicates that price limits do not work as well in corn futures as in soybean futures.

7. Discussion

From all the tests that we have done, we can see that, generally speaking, price limits work differently from what the overreaction theory predicts. However, we still can not say that overreaction does not exist at all. Neither can we say that price limits can not correct overreaction and reduce excess volatility at all. The reasons are as follows:

For corn futures in test 1a, except for Garman & Klass's estimate, the other three estimates indicate that from one day before a limit hit to one day after the limit hit, i.e. from t=-1 to t=1, the volatility of the rebound sample R has been reduced significantly. This result is consistent with the overreaction theory. Also for corn futures in test 4, we find some similar results when we compare the period before a limit hit with the period after the limit hit for those samples with limit hits. However, in general, the majority of our results do not support the overreaction theory.

One possible reason why overreaction is just a minor effect might be: overreaction is an irrational psychological effect of people, so individual investors may suffer more from this effect during their investment practices than financial institutions. Financial institutions such as investment companies may be more likely to base their investment decisions on quantitative methods (such as some investment software) than on personal intuition and therefore may be more likely to make rational decisions. On the other hand, it is those financial institutions which drive the market and play a major role, not individual investors. So, generally speaking, the market should be rational and the overreaction effect could be minor.

Another reason why overreaction is minor might be: overreaction is only an intra-day effect; overreaction can build up very quickly during the day and also can be corrected very quickly during the day. If this is true, our test results can not be used to disprove the overreaction theory. Our results depict the big picture of how price limits work. We can not see evidence consistent with the overreaction theory in this big picture; however, this theory may still play a role if we look at the details of the picture.

If we increase the resolution we can see more details of the big picture of how price limits work and then maybe we can find a trace of overreaction. Tests 2c and 2d divide limit hit occurrences into 2 and 3 categories according to the Nlimit/Ntotal value. None of the test results support the overreaction theory. However, if we go further and divide the occurrences into more and more categories, we increase the resolution and find some interesting results in table 7: overreaction is exhibited and corrected after several minutes following a limit hit.

Table 7a reports the results when we divide all limit hit occurrences into 12 categories according to Nlimit/Ntotal values for corn and table 7b for soybean (8 categories). Only the fifth (fourth for soybean) least constrained category Set (5/12) (Set (4/8) for soybean) shows significant less volatility than the adjacent less constrained category Set (4/12) (Set (3/8) for soybean) during 1, 2 and 3 days after a limit hit, which is consistent with overreaction theory. More interesting and more importantly, all other categories show results consistent with spillover effects.

This is consistent with our conjecture that the overreaction theory only works on an intra-day level. The Nlimit value of the categories mentioned in the last paragraph is around 2 to 4 minutes out of 225 minutes of a typical trading day (3 to 12 for soybean). This means the overreaction is corrected and the volatility is reduced within several minutes after a limit is hit.

Comparing corn with soybean we find that, except for test 3 and test 5, the results exhibit a different pattern. For example in test 1a, all tests on the different estimates of volatility indicate strong spillover effects for corn until 4 days after a limit hit, while for soybeans none of the estimates do that. Other tests such as test 2 and test 4 also report much stronger spillover effects for corn than for soybean. We believe the difference indicates that the limit level for corn is set too narrow. This causes the transaction to be suspended and delayed and increases volatility on the next day.

As we use event study methodology and the event is a limit hit, by and large, we can say that for corn futures our results reflect how limits work during the period before

August 1999, because most of the limit hit occurrences are before this month, as we illustrated in table 1a. As strong spillover effects are detected in our tests, we can say that before August 1999, the transactions are suspended and delayed and the market is less efficient. After the limit level increases to 20 cents/bushel in August 1999, there is almost no limit hit and the market is more efficient. The limit level of 10 cents/bushel or 12 cents/bushel before August 1999 is just set too narrow.

For soybean futures, for the same reason discussed in the last paragraph, our results reflect how limits work before August 2000. As less spillover effects are detected when compared with corn, we can say that, relatively speaking, price limit levels are more properly set for soybean futures before August 2004 than for corn before August 1999.

Ideally, the price limit level should be narrow enough to correct overreaction and reduce excess volatility, yet wide enough to avoid unnecessarily suspending and delaying transactions. Considering that the overreaction effect is just a minor effect, we propose that in most situations where the optimized limit level is unknown, we should set limit levels wider rather than narrower, to avoid delayed transactions and inefficient market prices.

8. Conclusion

Overreaction theory states that price limits can be used to correct for overreaction in the market and then reduce the excess volatility. However, our tests find little evidence supporting this theory. On the contrary, our results suggest strong spillover effects and provide strong evidence indicating that price limits mainly suspend transactions and delay price discovery and make the market less efficient.

This thesis mainly uses daily data which might be a limitation. Moreover, consecutive limit hit days are not distinguished in the tests and neither are upper and lower limit hit days.

Since the results indicate that the overreaction is minor on a daily level and is more likely an intra-day effect, further tests should be on an intra-day level and use more tick data. We believe that this will help us determine whether the overreaction theory holds on an intra-day level. We can also go further from test 6 using tick data. The results may give a helping hand when we are trying to determine the optimal limit level for future contracts. Of course, more tests on contracts other than corn and soybean will also be worthwhile.

9. References

Anderson, R. W., (1984): The industrial organization of futures markets: A survey, in: Ronald W. Anderson, ed., The Industrial Organization of Futures Markets.

Brennan, M. J., (1986): A theory of price limits in futures markets, Journal of Financial Economics, 16, 213-233.

Chen, H., (1998): Price limits, overreaction, and price resolution in futures markets, Journal of Futures Markets, 5, 243-263.

Chen, H., (2002): Price limits and margin requirements in futures markets, Financial Review, 37, 105-121.

Chou, P. H., Lin, M. C., Yu, M. T., (2000): Price limits, margin requirements, and default risk, Journal of Futures Markets, 20, 6, 573-602

Daniel, K., Hirshleifer, D., and Subrahmanyam, A., (1998): Investor psychology and security market under- and overreactions, Journal of Finance, 56, 921-965.

De Bondt, W., and Thaler, R. H., (1985): Does the stock market overreact? Journal of Finance, 40, 793-804.

De Bondt, W., and Thaler, R. H., (1990): Do security analysts overreact? American Economic Review, 2, 52-57.

Evans, J., and Mahoney, J. M., (1997): The effects of price limits on trading volume: A study of the cotton futures market, Current Issues in Economics and Finance, Jan, 3, 2.

Garman, M., and Klass, M., (1980): On the estimation of security price volatility from historical data, Journal of Business, 53, 67-78.

Gay, G., Kale, J., Kolb, R., and Note, T., (1994): (Micron) Fads in asset prices: evidence from the futures markets, Journal of Futures Markets, 6, 637-659.

Harrington, C., (2003): Beyond belief, CFA Magazine, Sept-Oct 2003, 26-31.

Hieronymus, T. A., (1971): Economics of futures trading, Commodity Research Bureau, New York.

Kahneman, D., and Tversky, A., (1981): Intuitive prediction biases and corrective procedures, Judgment under Uncertainty: Heuristics and Biases, Cambridge University Press.

Kodres, L. E., and O'Brien, D. P., (1994): The existence of Pareto superior price limits and trading halts, American Economic Review, 4, 919-932.

Kim, K., A., and Rhee, S. G., (1997): Price limit performance: evidence from the Tokyo stock exchange, Journal of Finance, 52, 2, 885-899.

Lin, M. C., and Chou, P. H., (2002): The effectiveness of price limits when investors are overconfident, http://www.fin.ntu.edu.tw/students/college/021217.pdf, October 2002.

Ma, C. K., Rao, R. P., and Sears, S., (1989): Limits moves and price resolution: The case of the Treasury bond futures market, Journal of Futures Markets, 9, 321-335.

Ma, C. K., Dare, W. H., and Donaldson, D. R., (1990): Testing rationality in futures markets, Journal of Futures Markets, 2, 137-152.

Parkinson, M., (1980): The extreme value method for estimating the variance of the rate of return, Journal of Business, 53, 61-65.

Shefrin, H., (1978): Differential information and informational equilibrium, Economics Letters, 1.

Shefrin, H., (1999): Beyond Greed and Fear: Understanding Behavioral Finance and the Psychology of Investing, Harvard Business School Press.

Shiller, R., (1978): Rational expectations and the dynamic structure of macroeconomic models: a critical review, Journal of Monetary Economics, 4, 1-44.

Shiller, R., (2000): Irrational Exuberance, Princeton University Press.

Shaw, C., Williams, K., Assassa, R. P., (2000): Information point: Wilcoxon Signed Rank Test, Journal of Clinical Nursing, 9, 584

Thaler, R., (1976): On optimal speed limits, Auto Safety Regulation: The Cure or the Problem?

Thaler, R., (1996): Doing economics without homo economicus, Exploring the Foundations of Research in Economics: How Should Economists Do Economics?

Telser, L., (1981): Margins and futures contracts, Journal of Futures Markets, 1, 225-253.

Wiggins, J. B., (1992): Estimating the volatility of S&P 500 futures prices using the extreme-value method, Journal of Futures Markets, 12, 3, 265-273.

Table 1a: CBOT Historical Daily Price Limits and Number of Limit Hit Days During 07/01/82-11/30/04

Corn Futures		
Period	Daily Price Limit (cents/bushel)	Number of Limit Hit Days
07/01/82-07/14/93	10	99
07/15/93-08/26/99	12	66
08/27/99-11/30/04	20	2

Soybean Futures		
Period	Daily Price Limit (cents/bushel)	Number of Limit Hit Days
07/01/82-8/25/00	30	120
08/27/00-11/30/04	50	8

Note: Historical expanded limit levels are not included but they are also counted when determining the number of limit hit days.

Table 1b: Number of Limit Hit Days by Year

Year	Corn	Soybean
1982*	1	0
1983	21	26
1984	3	10
1985	0	0
1986	5	1
1987	5	5
1988	37	30
1989	10	6
1990	2	1
1991	9	7
1992	4	1
1993	3	2
1994	6	5
1995	2	3
1996	41	6
1997	7	13
1998	5	2
1999	4	1
2000	0	1
2001	0	0
2002	0	0
2003	0	0
2004**	2	8
Total	167	128

* 1982 data begins in July.

** 2004 data ends in November.

Table 1c: Summary Statistics for Corn and Soybean Futures

	Mean of closing price (cents/bushel)		Standard deviation of closing price (cents/bushel)	
Year	Corn	Soybean	Corn	Soybean
1982*	235.91	569.32	13.93	26.77
1983	318.53	714.58	31.88	120.63
1984	312.61	704.57	30.66	88.38
1985	253.78	554.05	22.69	37.84
1986	201.05	510.75	33.37	24.00
1987	174.18	532.25	13.93	35.37
1988	255.89	767.32	46.09	110.44
1989	254.3	670.67	18.89	85.85
1990	251.89	601.64	21.01	22.91
1991	247.42	572.01	8.68	19.98
1992	239.91	571.82	22.94	23.16
1993	240.3	627.69	24.04	45.91
1994	251.06	624.02	31.56	59.82
1995	281.74	614.03	37.23	50.37
1996	363.97	752.91	69.82	41.92
1997	275.12	746.25	17.32	81.24
1998	239.14	604.56	23.23	53.33
1999	212.54	478.61	10.70	25.10
2000	212.78	501.71	18.35	30.16
2001	211.8	459.81	10.22	25.42
2002	229.77	512.34	25.00	50.96
2003	233.99	633.53	11.45	79.02
2004**	259.69	760.52	42.31	179.58

* 1982 data begins in July.

** 2004 data ends in November.

Table 2a: Comparison of Volatility of the Rebound Sample and the Benchmark Sample Using the Four Measures of Volatility

This table reports Wilcoxon Signed-Rank Test results for the null hypothesis that price limits do not affect the price volatility of futures contracts. Daily volatility of the rebound sample R and the benchmark sample N are compared from 5 days before limit-hit to 5 days after limit-hit for both corn and soybean futures. Here we define closing%=$(C_t-C_{t-1})/L$ where C_t is the closing price on day t, C_{t-1} is the previous day's closing price and L is the price limit of the day. Sample R and sample N are matched by closing% value. Daily volatility is calculated using four measures: 1) classical volatility estimate, 2) Parkinson's (1980) estimate based on daily high and low prices, 3) Garman and Klass's (1980) estimate of volatility, and 4) Kim and Rhee's (1997) estimate of volatility. All Kim and Rhee's estimates are multiplied by 10000 in the table.

Panel A: Corn Futures

	Measure of Volatility							
	Classical	–	Kim & Rhee	–	Parkinson	–	Garman & Klass	
Day	Sample N	Sample R	Sample N	Sample R	Sample N	Sample R	Sample N	Sample R
-5	20.697	**58.207**[a]	2.402	**5.465**[a]	12.904	**23.222**[a]	12.828	**20.766**[b]
-4	17.081	47.386b	2.154	4.796	14.363	21.997	12.169	**21.657**[b]
-3	22.744	39.474	2.532	3.611	10.543	15.042	8.838	**16.029**[b]
-2	22.725	**51.776**[b]	2.451	**4.167**[b]	8.434	**17.073**[a]	8.156	**16.257**[b]
-1	20.058	**58.118**[a]	2.170	**5.296**[b]	7.333	**17.248**[b]	7.416	**17.777**[a]
0	49.431	46.682	6.225	5.635	14.569	**46.525**[a]	11.815	**47.172**[a]
1	21.317	21.614	2.397	2.177	11.834	18.588	11.501	**19.282**[b]
2	20.073	**44.345**[a]	2.256	**3.974**[b]	11.306	**24.244**[b]	12.788	**20.877**[a]
3	12.807	**45.922**[a]	1.693	**3.676**[b]	8.888	**18.227**[b]	9.644	13.502
4	16.144	**42.459**[b]	1.903	**4.479**[b]	8.044	21.330	8.027	21.327
5	25.094	40.513	2.764	3.765	8.756	**27.404**[a]	8.528	**27.329**[a]

	Panel B: Soybean Futures							
	Measure of Volatility							
	Classical		Kim & Rhee		Parkinson		Garman & Klass	
Day	Sample N	Sample R	Sample N	Sample R	Sample N	Sample R	Sample N	Sample R
-5	186.883	321.945	3.210	5.716	149.655	132.492	152.162	117.732
-4	206.137	215.547	3.139	3.666	137.140	204.241	120.141	211.602
-3	187.216	249.328	2.996	3.503	114.247	183.422	120.595	160.440
-2	236.685	165.617	3.563	2.752	97.440	130.160	94.509	135.535
-1	259.898	292.817	3.806	4.021	133.507	136.193	121.659	102.846
0	557.922	**463.765**[d]	9.281	9.157	234.681	301.682	167.834	324.690
1	280.081	254.120	4.467	4.317	195.498	166.803	188.010	159.555
2	149.953	274.573	2.381	3.971	136.268	133.477	131.233	120.637
3	239.132	422.329	3.491	5.946	122.776	145.652	113.194	131.098
4	196.332	200.178	3.038	3.311	109.490	119.856	114.902	124.147
5	340.998	294.704	5.577	5.227	164.821	198.466	116.739	202.232

[a]: the volatility of the rebound sample R is significantly greater than that of the benchmark sample N at the 0.01 level of significance. [b]: the volatility of the rebound sample R is significantly greater than that of the benchmark sample N at the 0.05 level of significance. [d]: the volatility of the rebound sample R is significantly less than that of the benchmark sample N at the 0.05 level of significance.

Table 2b: Comparison of Volatility of the Rebound Sample R85 and the Benchmark Sample N85 Using the Four Measures of Volatility

This table reports Wilcoxon Signed-Rank Test results for the null hypothesis that price limits do not affect the price volatility of futures contracts. Here we define closing%=$P_c/L=(C_t-C_{t-1})/L$ where P_c is the normalized closing price, C_t is the closing price on day t, C_{t-1} is the previous day's closing price and L is the price limit of the day. Daily volatility of the rebound sample R80 (which has limit-hit and $|P_c/L|\geq 80\%$) and the benchmark sample N80 (which has no limit-hit and $|P_c/L|\geq 80\%$) are compared from 5 days before limit-hit to 5 days after limit-hit for corn futures and also the rebound sample R85 (which has limit-hit and $|P_c/L|\geq 85\%$) and its benchmark sample N85 (which has no limit-hit and $|P_c/L|\geq 85\%$) are compared for soybean futures. Sample R80 (R85 for soybeans) and sample N80 (N85 for soybeans) are matched by closing% value. Daily volatility is calculated using four measures: 1) classical volatility estimate, 2) Parkinson's (1980) estimate based on daily high and low prices, 3) Garman and Klass's (1980) estimate of volatility, and 4) Kim and Rhee's (1997) estimate of volatility. All Kim and Rhee's estimates are multiplied by 10000 in the table.

Panel A: Corn Futures

	Measure of Volatility							
	Classical		Kim & Rhee		Parkinson		Garman & Klass	
Day	N80	R80	N80	R80	N80	R80	N80	R80
-5	44.794	22.584	3.859	2.984	37.512	21.221	41.783	22.417
-4	28.506	30.928	3.291	2.572	38.290	19.631	33.513	14.028
-3	67.825	27.473	6.266	2.127	21.113	13.085	10.936	14.625
-2	56.100	31.723	5.214	3.977	15.482	27.040	12.973	26.968
-1	52.563	21.405	4.347	3.003	10.270	14.040	10.618	15.734
0	107.238	102.988	11.076	11.481	28.207	32.996	20.625	32.202
1	49.631	21.347	4.451	2.323	25.049	17.645	19.871	22.058
2	51.313	16.541	4.516	1.455	18.829	18.408	24.648	22.196
3	12.356	**45.891**[b]	1.229	**3.747**[b]	15.439	31.135	18.278	27.184
4	40.394	48.714	3.020	4.096	7.473	15.789	8.525	14.062
5	80.113	54.206	6.724	6.208	13.417	22.160	11.849	20.870

Panel B: Soybean Futures

Measure of Volatility

	Classical		Kim & Rhee		Parkinson		Garman & Klass	
Day	N85	R85	N85	R85	N85	R85	N85	R85
-5	262.005	561.545	4.090	8.064	173.206	199.880	164.806	143.872
-4	418.505	328.068	5.563	4.129	228.953	155.751	174.816	130.866
-3	260.073	233.483	3.852	3.400	222.829	142.065	259.608	**135.579**[d]
-2	278.443	206.889	3.874	2.958	142.269	162.098	123.366	139.898
-1	354.583	260.082	4.774	3.721	155.062	172.856	171.021	105.398
0	906.880	**739.083**[c]	13.975	11.779	252.295	408.435	140.631	312.496
1	95.818	**267.665**[b]	1.473	**3.301**[b]	161.800	125.380	175.679	117.128
2	259.609	285.212	3.929	3.538	149.261	199.800	137.566	220.255
3	329.839	391.394	4.334	5.514	124.200	161.628	122.305	159.841
4	477.943	253.906	7.669	3.489	233.602	141.131	159.238	114.516
5	353.323	299.734	4.665	4.478	138.732	110.822	111.288	108.226

[b]: the volatility of the rebound sample R80 (R85 for soybeans) is significantly greater than that of the benchmark sample N80 (N85 for soybeans) at the 0.05 level of significance. [c]: the volatility of the rebound sample R80 (R85 for soybeans) is significantly less than that of the benchmark sample N80 (N85 for soybean) at the 0.01 level of significance. [d]: the volatility of the rebound sample R80 (R85 for soybeans) is significantly less than that of the benchmark sample N80 (N85 for soybeans) at the 0.05 level of significance.

Table 3a: Comparison of Volatility of Different Samples Which Have Different Nlimit/Ntotal Values Using the Four Measures of Volatility

This table reports Wilcoxon Signed-Rank Test results for the null hypothesis that price limits do not affect the price volatility of futures contracts. Nlimit/Ntotal is defined as the number of minutes the futures contract trading is constrained by its limit price (Nlimit) over the total minutes of the trading day (Ntotal). Daily volatility of Sample5 whose Nlimit/Ntotal≤5% and Sample96 whose Nlimit/Ntotal≥96% are compared from 5 days before limit-hit to 5 days after limit-hit for corn futures and Sample7 whose Nlimit/Ntotal≤7% and Sample97 whose Nlimit/Ntotal≥97% are compared for soybean futures. Daily volatility is calculated using four measures: 1) classical volatility estimate, 2) Parkinson's (1980) estimate based on daily high and low prices, 3) Garman and Klass's (1980) estimate of volatility, and 4) Kim and Rhee's (1997) estimate of volatility. All Kim and Rhee's estimates are multiplied by 10000 in the table.

Panel A: Corn Futures

	Measure of Volatility							
	Classical		Kim & Rhee		Parkinson		Garman & Klass	
Day	Sample5	Sample96	Sample5	Sample96	Sample5	Sample96	Sample5	Sample96
-5	37.184	**84.059**[b]	3.893	7.630	17.110	29.360	17.561	22.211
-4	33.147	**96.242**[b]	3.377	7.796	15.952	**48.120**[b]	14.751	37.680
-3	27.173	68.777	2.702	5.382	16.185	**46.678**[b]	18.098	**48.335**[b]
-2	40.624	**78.863**[b]	4.070	7.722	16.422	34.804	15.727	30.346
-1	37.785	65.965	3.806	6.350	16.796	33.312	16.117	22.956
0	78.756	**133.559**[a]	9.692	12.810	36.716	**7.873**[c]	34.841	**3.751**[c]
1	30.229	**111.992**[a]	3.286	**9.892**[a]	16.543	**51.934**[b]	16.216	**43.411**[b]
2	44.753	74.430	4.709	5.589	16.400	28.495	14.016	29.977
3	39.002	50.695	3.324	4.361	14.696	**41.903**[b]	13.999	**44.834**[b]
4	30.948	53.637	3.526	4.036	16.607	23.654	17.098	27.000
5	30.402	46.348	3.376	4.147	20.966	46.248	20.144	46.900

Panel B: Soybean Futures

	Measure of Volatility							
	Classical		Kim & Rhee		Parkinson		Garman & Klass	
Day	Sample7	Sample97	Sample7	Sample97	Sample7	Sample97	Sample7	Sample97
-5	342.452	565.852	5.297	6.818	159.607	324.100	139.145	363.986
-4	225.233	**573.188**[b]	3.210	**7.639**[b]	142.068	359.241	139.468	402.960
-3	241.406	544.023	3.374	6.932	158.770	292.220	147.910	362.856
-2	192.639	648.824	3.026	8.173	164.471	145.384	148.506	148.594
-1	236.815	455.068	3.235	5.889	146.883	120.961	112.765	101.141
0	695.922	**1125.591**[a]	12.612	15.875	315.239	**2.797**[c]	276.001	**3.032**[c]
1	229.246	**727.483**[b]	3.517	**9.016**[b]	142.463	205.076	142.147	139.799
2	332.957	693.347	4.757	7.892	153.290	238.684	146.915	188.112
3	278.991	631.369	4.188	7.152	153.147	216.404	141.884	203.413
4	260.865	700.574	3.822	8.157	150.642	250.242	162.114	265.530
5	255.339	521.011	4.622	6.566	126.338	294.740	115.463	284.334

[a]: the volatility of Sample96 (Sample97 for soybeans) is significantly greater than that of the benchmark Sample5 (Sample7 for soybeans) at the 0.01 level of significance. [b]: the volatility of Sample96 (Sample97 for soybeans) is significantly greater than that of the benchmark Sample5 (Sample7 for soybeans) at the 0.05 level of significance. [c]: the volatility of Sample96 (Sample97 for soybeans) is significantly less than that of the benchmark Sample5 (Sample7 for soybeans) at the 0.01 level of significance.

Table 3b: Comparison of Volatility of Sample0 and Sample100 Using the Four Measures of Volatility

This table reports Wilcoxon Signed-Rank Test results for the null hypothesis that price limits do not affect the price volatility of futures contracts. Nlimit/Ntotal is defined as the number of minutes the futures contract trading is constrained by its limit price (Nlimit) over the total minutes of the trading day (Ntotal). Daily volatility of Sample0 whose Nlimit/Ntotal~0% and Sample100 whose Nlimit/Ntotal~100% are compared from 5 days before limit-hit to 5 days after limit-hit for both corn and soybean futures. Daily volatility is calculated using four measures: 1) classical volatility estimate, 2) Parkinson's (1980) estimate based on daily high and low prices, 3) Garman and Klass's (1980) estimate of volatility, and 4) Kim and Rhee's (1997) estimate of volatility. All Kim and Rhee's estimates are multiplied by 10000 in the table.

Panel A: Corn Futures

	Measure of Volatility							
	Classical		Kim & Rhee		Parkinson		Garman & Klass	
Day	Sample0	Sample100	Sample0	Sample100	Sample0	Sample100	Sample0	Sample100
-5	24.782	**92.188**[a]	3.600	**8.403**[b]	12.785	34.295	14.926	24.716
-4	26.741	**114.722**[b]	3.494	**9.969**[b]	13.102	**51.259**[b]	12.075	**38.842**[b]
-3	23.803	72.966	2.967	6.360	9.865	**42.299**[a]	10.718	**46.638**[a]
-2	28.034	**102.466**[a]	3.466	**10.616**[a]	16.107	32.883	16.363	23.278
-1	24.557	**79.545**[b]	3.481	**8.228**[b]	12.674	36.844	15.428	18.452
0	64.968	**136.801**[a]	8.589	**14.188**[a]	28.737	**0.000**[c]	29.535	**0.000**[c]
1	32.091	**89.699**[b]	3.712	**9.537**[b]	13.842	**55.486**[a]	13.867	**48.788**[b]
2	44.097	61.318	4.777	5.254	16.767	18.636	13.781	22.294
3	44.063	56.386	3.735	5.216	12.331	46.322	11.798	**54.010**[b]
4	30.835	51.784	3.788	4.242	15.424	30.368	16.632	34.627
5	31.244	40.653	3.663	3.520	19.222	**62.276**[b]	19.102	**64.911**[b]

Panel B: Soybean Futures

Measure of Volatility

Day	Classical		Kim & Rhee		Parkinson		Garman & Klass	
	Sample0	Sample100	Sample0	Sample100	Sample0	Sample100	Sample0	Sample100
-5	337.174	588.819	5.363	7.044	139.289	257.223	113.575	254.810
-4	265.685	**606.118**[b]	3.778	**8.082**[a]	147.978	337.563	135.160	382.374
-3	275.400	549.361	3.751	7.093	186.787	212.086	166.728	258.478
-2	171.715	691.229	2.794	**8.686**[b]	134.156	123.150	128.845	116.683
-1	283.803	437.417	3.893	5.583	159.875	131.809	112.407	105.669
0	561.544	**1182.278**[a]	11.093	**16.946**[a]	361.349	**0.013**[c]	353.596	**0.018**[c]
1	250.188	769.590	4.087	9.595	160.324	208.970	154.180	146.714
2	266.144	734.396	3.859	8.367	164.558	167.844	166.357	130.390
3	334.481	671.229	4.959	7.677	132.851	230.791	120.307	226.864
4	226.275	541.007	3.434	6.721	105.683	242.513	106.115	257.822
5	245.836	540.257	4.279	6.894	102.498	**269.766**[b]	95.742	245.852

[a]: the volatility of Sample100 is significantly greater than that of the benchmark Sample0 at the 0.01 level of significance. [b]: the volatility of Sample100 is significantly greater than that of the benchmark Sample0 at the 0.05 level of significance. [c]: the volatility of Sample100 is significantly less than that of the benchmark Sample0 at the 0.01 level of significance.

Table 3c: Comparison of Volatility of Sample S and Sample L Using the Four Measures of Volatility

This table reports Wilcoxon Signed-Rank Test results for the null hypothesis that price limits do not affect the price volatility of futures contracts. Nlimit/Ntotal is defined as the number of minutes the futures contract trading is constrained by its limit price (Nlimit) over the total minutes of the trading day (Ntotal). Daily volatility of Sample S (which contains the first half of the occurrences which have smaller Nlimit/Ntotal) and Sample L (which contains the second half of the occurrences which have larger Nlimit/Ntotal) are compared from 5 days before limit-hit to 5 days after limit-hit for both corn and soybean futures. Daily volatility is calculated using four measures: 1) classical volatility estimate 2) Parkinson's (1980) estimate based on daily high and low prices 3) Garman and Klass's (1980) estimate of volatility 4) Kim and Rhee's (1997) estimate of volatility. All Kim and Rhee's estimates are multiplied by 10000 in the table.

Panel A: Corn Futures

	Measure of Volatility							
	Classical		Kim & Rhee		Parkinson		Garman & Klass	
Day	Sample S	Sample L	Sample S	Sample L	Sample S	Sample L	Sample S	Sample L
-5	36.545	**77.414**^{a}	3.927	**7.055**^{a}	17.022	**28.990**^{a}	17.217	**25.645**^{a}
-4	32.901	**71.973**^{a}	3.456	**5.918**^{a}	16.070	**42.260**^{a}	15.143	**39.088**^{a}
-3	23.532	**70.522**^{a}	2.545	**5.131**^{b}	17.040	**38.612**^{a}	19.144	**37.139**^{a}
-2	38.648	66.484	3.934	5.342	16.253	**35.019**^{a}	15.698	**34.708**^{a}
-1	39.670	**59.609**^{b}	3.997	4.775	16.616	**32.810**^{a}	15.940	**27.859**^{a}
0	77.859	**137.615**^{a}	9.696	**12.865**^{b}	38.275	**25.817**^{c}	36.528	**16.717**^{c}
1	31.257	**76.826**^{a}	3.410	**6.020**^{b}	17.159	**42.785**^{a}	16.670	**44.385**^{a}
2	47.260	60.234	4.969	4.704	16.721	**39.198**^{a}	14.027	**37.936**^{a}
3	40.568	**64.247**^{a}	3.452	**5.223**^{b}	15.116	**39.009**^{a}	14.311	**33.283**^{a}
4	32.693	**65.947**^{a}	3.726	5.014	17.173	**29.080**^{a}	17.596	**29.612**^{a}
5	30.973	**63.170**^{b}	3.480	5.251	21.578	**37.329**^{b}	20.958	36.763

Panel B: Soybean Futures

	Measure of Volatility							
	Classical		Kim & Rhee		Parkinson		Garman & Klass	
Day	Sample S	Sample L	Sample S	Sample L	Sample S	Sample L	Sample S	Sample L
-5	330.964	426.983	5.200	5.966	160.467	196.073	142.844	198.515
-4	219.669	**365.520**[a]	3.170	**5.331**[a]	141.974	**255.281**[b]	137.959	257.731
-3	236.891	**379.511**[b]	3.356	**5.345**[b]	161.469	204.767	148.085	210.737
-2	192.189	405.650	3.103	5.414	132.647	204.238	130.960	170.044
-1	231.458	277.620	3.193	3.853	143.003	158.396	105.056	154.782
0	673.927	**1003.366**[a]	12.667	**15.111**[b]	320.618	**145.123**[c]	283.681	**91.785**[c]
1	223.033	**469.447**[b]	3.480	6.484	132.247	199.947	133.017	183.195
2	319.914	**551.988**[b]	4.639	6.874	141.181	216.314	140.817	169.919
3	284.764	417.552	4.298	5.228	153.579	181.614	139.404	168.777
4	243.852	**438.977**[b]	3.652	5.662	151.710	186.880	162.014	189.799
5	253.967	353.242	4.705	4.665	113.094	**265.008**[a]	105.678	**267.671**[a]

[a]: the volatility of Sample L is significantly greater than that of the benchmark Sample S at the 0.01 level of significance. [b]: the volatility of Sample L is significantly greater than that of the benchmark Sample S at the 0.05 level of significance. [c]: the volatility of Sample L is significantly less than that of the benchmark Sample S at the 0.01 level of significance.

Table 3d: Comparison of Volatility of Samples SS, Sample M and Sample LL
Using the Four Measures of Volatility

This table reports Wilcoxon Signed-Rank Test results for the null hypothesis that price limits do not affect the price volatility of futures contracts. Nlimit/Ntotal is defined as the number of minutes the futures contract trading is constrained by its limit price (Nlimit) over the total minutes of the trading day (Ntotal). Daily volatility of Sample SS (which contains the first one-third of the occurrences which have smaller Nlimit/Ntotal) and Sample LL (which contains the last one-third of the occurrences which have larger Nlimit/Ntotal) are compared with benchmark Sample M (which contains the second one-third of the occurrences which have medium Nlimit/Ntotal) from 5 days before limit-hit to 5 days after limit-hit for both corn and soybean futures. Daily volatility is calculated using four measures: 1) classical volatility estimate, 2) Parkinson's (1980) estimate based on daily high and low prices, 3) Garman and Klass's (1980) estimate of volatility, and 4) Kim and Rhee's (1997) estimate of volatility. All Kim and Rhee's estimates are multiplied by 10000 in the table.

Panel A: Corn Futures

	Measure of Volatility											
	Classical			Kim & Rhee			Parkinson			Garman & Klass		
Day	SS	M	LL	SS	M	LL	SS	M	LL	SS	M	LL
-5	37.573	54.458	**78.900**^{b}	3.881	5.409	7.184	16.204	24.503	27.706	16.513	22.607	24.573
-4	33.277	40.009	**83.463**^{a}	3.521	3.773	**6.734**^{b}	18.514	20.130	**48.320**^{a}	17.561	19.769	43.288
-3	31.203	38.561	**71.200**^{b}	3.205	3.436	4.868	14.480	19.175	**49.337**^{a}	14.942	21.693	**47.119**^{a}
-2	37.992	43.778	**72.405**^{b}	4.002	4.031	5.674	18.375	22.052	**36.260**^{a}	17.503	24.043	**33.924**^{a}
-1	40.555	36.123	**70.983**^{a}	4.040	3.056	**5.994**^{a}	15.801	17.896	**38.710**^{a}	16.554	17.113	**29.712**^{b}
0	78.034	88.834	**155.242**^{a}	9.154	10.683	**14.058**^{b}	41.274	33.601	**20.295**^{c}	**38.102**^{b}	27.037	**12.984**^{c}
1	**32.627**^{b}	27.433	**98.917**^{a}	3.634	2.624	**7.727**^{a}	18.402	19.343	**51.146**^{a}	17.567	21.301	**52.308**^{a}
2	43.183	41.234	68.727	4.825	3.900	5.290	**15.418**^{d}	24.258	**44.041**^{b}	12.993	21.534	**43.361**^{a}
3	45.508	32.456	**74.359**^{a}	3.629	3.142	**5.913**^{b}	16.284	20.183	**43.773**^{a}	14.516	16.113	**39.638**^{a}
4	30.884	45.480	71.483	3.445	4.035	5.639	20.822	12.335	**34.536**^{a}	21.540	11.576	**36.062**^{a}
5	30.573	33.719	**73.336**^{b}	3.284	3.459	6.090	21.288	25.796	**40.934**^{b}	21.140	25.778	**39.360**^{b}

Panel B: Soybean Futures

	Measure of Volatility											
	Classical			Kim & Rhee			Parkinson			Garman & Klass		
Day	SS	M	LL	SS	M	LL	SS	M	LL	SS	M	LL
-5	337.174	312.398	485.648	5.363	4.661	6.698	139.289	197.672	195.337	113.575	184.273	209.837
-4	265.685	171.123	**445.704**[a]	3.778	2.362	**6.669**[a]	147.978	199.393	249.504	135.160	207.896	251.933
-3	275.400	231.486	410.384	3.751	3.287	5.907	186.787	143.233	215.761	166.728	139.381	229.785
-2	171.715	322.451	392.542	2.794	4.360	5.476	134.156	242.121	126.902	128.845	207.174	115.224
-1	283.803	164.157	314.843	**3.893**[b]	2.218	4.439	159.875	127.393	162.563	112.407	124.887	150.167
0	**561.544**[c]	975.275	981.391	**11.093**[d]	15.406	15.104	361.349	271.035	**64.668**[c]	**353.596**[a]	162.840	**43.226**[c]
1	250.188	234.319	**542.722**[a]	4.087	3.020	**7.675**[a]	160.324	137.150	200.555	154.180	146.036	174.836
2	266.144	490.308	535.275	3.859	6.367	6.832	164.558	164.337	201.809	166.357	127.387	167.783
3	334.481	350.292	377.475	4.959	4.750	4.714	132.851	201.077	168.830	120.307	179.368	162.630
4	226.275	366.611	418.859	3.434	5.059	5.308	**105.683**[d]	256.032	140.754	**106.115**[d]	261.984	153.931
5	245.836	291.736	373.340	4.279	4.904	4.870	**102.498**[c]	277.058	186.485	**95.742**[c]	283.303	178.300

[a]: the volatility of Sample LL (SS) is significantly greater than that of the benchmark Sample M at the 0.01 level of significance. [b]: the volatility of Sample LL (SS) is significantly greater than that of the benchmark Sample M at the 0.05 level of significance. [c]: the volatility of Sample LL (SS) is significantly less than that of the benchmark Sample M at the 0.01 level of significance. [d]: the volatility of Sample LL (SS) is significantly less than that of the benchmark Sample M at the 0.05 level of significance.

Table 4a: Comparison of Volatility of the Uplock Sample U and the Benchmark Sample N(+80) Using the Four Measures of Volatility

This table reports Wilcoxon Signed-Rank Test results for the null hypothesis that price limits do not affect the price volatility of futures contracts. Here we define closing%=$P_c/L=(C_t-C_{t-1})/L$ where P_c is the normalized closing price, C_t is the closing price on day t, C_{t-1} is the previous day's closing price and L is the price limit of the day. Daily volatility of the Uplock sample U (whose closing price is locked at the up-limit price) and the benchmark sample N(+80) (which has no limit-hit and (P_c/L)≥80%) are compared from 5 days before limit-hit to 5 days after limit-hit for corn futures only since not enough occurrences are found for soybean futures for this test. Daily volatility is calculated using four measures: 1) classical volatility estimate, 2) Parkinson's (1980) estimate based on daily high and low prices, 3) Garman and Klass's (1980) estimate of volatility, and 4) Kim and Rhee's (1997) estimate of volatility. All Kim and Rhee's estimates are multiplied by 10000 in the table.

	Corn Futures							
	Measure of Volatility							
	Classical		Kim & Rhee		Parkinson		Garman & Klass	
Day	N(+80)	U	N(+80)	U	N(+80)	U	N(+80)	U
-5	35.183	61.212	2.168	**5.589**^{b}	68.048	25.164	69.199	22.176
-4	30.929	72.031	2.116	6.236	41.270	34.283	40.720	25.671
-3	57.563	66.571	4.156	4.914	32.759	37.005	19.137	**32.905**^{b}
-2	66.518	77.078	5.168	6.636	21.471	32.664	19.063	28.757
-1	100.335	49.984	7.045	4.897	12.434	**32.000**^{b}	13.127	25.229
0	104.281	**139.259**^{b}	9.064	**14.904**^{b}	40.495	11.339	30.114	**7.410**^{c}
1	48.563	55.281	3.293	4.944	44.081	47.075	31.750	49.805
2	60.656	49.013	4.651	3.892	11.699	35.009	13.812	34.792
3	22.076	60.647	1.557	4.478	24.004	35.657	27.237	32.441
4	79.161	69.960	4.840	5.522	12.933	29.174	13.101	29.161
5	107.585	43.397	6.718	3.566	18.344	36.786	18.818	40.350

[b]: the volatility of the uplock sample U is significantly greater than that of the benchmark sample N80 at the 0.05 level of significance. [c]: the volatility of the uplock sample U is significantly less than that of the benchmark sample N80 at the 0.01 level of significance.

Table 4b: Comparison of Volatility of the Downlock Sample D and the Benchmark Sample N(-85) Using the Four Measures of Volatility

This table reports Wilcoxon Signed-Rank Test results for the null hypothesis that price limits do not affect the price volatility of futures contracts. Here we define closing%=$P_c/L=(C_t-C_{t-1})/L$ where P_c is the normalized closing price, C_t is the closing price on day t, C_{t-1} is the previous day's closing price and L is the price limit of the day. Daily volatility of the Downlock sample D (whose closing price is locked at the down-limit price) and the benchmark sample N(-85) (which has no limit-hit and $(P_c/L) \leq -85\%$) are compared from 5 days before limit-hit to 5 days after limit-hit for soybean futures only since not enough occurrences are found for corn futures for this test. Daily volatility is calculated using four measures: 1) classical volatility estimate, 2) Parkinson's (1980) estimate based on daily high and low prices, 3) Garman and Klass's (1980) estimate of volatility, and 4) Kim and Rhee's (1997) estimate of volatility. All Kim and Rhee's estimates are multiplied by 10000 in the table.

	Soybean Futures							
	Measure of Volatility							
	Classical		Kim & Rhee		Parkinson		Garman & Klass	
Day	N(-85)	D	N(-85)	D	N(-85)	D	N(-85)	D
-5	311.694	516.424	4.912	7.146	181.850	165.591	154.358	158.147
-4	441.285	215.514	6.006	**2.861**[d]	288.900	172.397	214.187	176.766
-3	223.257	270.545	3.399	3.340	273.451	177.173	320.122	162.365
-2	230.722	468.944	3.154	6.146	175.601	293.285	153.767	219.812
-1	363.750	289.167	4.952	3.960	198.481	221.605	221.773	204.557
0	973.278	1142.503	14.945	15.668	263.104	275.034	148.482	169.909
1	122.361	**547.233**[a]	1.892	**8.031**[b]	145.943	232.841	163.355	242.081
2	276.257	**681.003**[b]	4.254	8.667	115.656	248.968	119.161	187.609
3	348.917	300.351	4.762	4.197	108.032	186.418	107.690	180.702
4	504.306	327.319	8.534	4.230	281.649	132.724	178.162	125.312
5	369.424	332.431	4.821	4.604	97.402	146.109	86.108	123.613

[a]: the volatility of the downlock sample D is significantly greater than that of the benchmark sample N(-85) at the 0.01 level of significance. [b]: the volatility of the downlock sample D is significantly greater than that of the benchmark sample N(-85) at the 0.05 level of significance. [d]: the volatility of the downlock sample D is significantly less than that of the benchmark sample N(-85) at the 0.05 level of significance.

Table 5: Comparison of Volatility of Different Samples in Different Time Windows Using Standard Deviation as the Traditional Measure of Volatility

This table reports Wilcoxon Signed-Rank Test results for the null hypothesis that price limits do not affect the price volatility of futures contracts. Volatility of several samples are compared with their benchmark samples during the time window t= [-5, -1], [-4, -1], [-3, -1], [1, 3], [1, 4], [1, 5] while t=0 is the limit-hit day. Volatility is calculated using the traditional estimate which is the standard deviation of the return during the period.

Panel A: Corn Futures

Time Window	SampleN	SampleR	N80	R80	Sample5	Sample96	Sample0	Sample100	S	L	SS	M	LL	N(+80)	U
[-5, -1]	1.766	**3.309**^{a}	3.116	1.948	2.705	**5.349**^{b}	2.430	**6.698**^{a}	2.809	**4.125**^{b}	2.767	2.916	**4.694**^{a}	2.443	**4.463**^{b}
[-4, -1]	1.394	**2.818**^{a}	1.999	1.900	2.262	**5.535**^{b}	2.018	**7.090**^{a}	2.333	**3.779**^{a}	2.219	2.299	**4.636**^{a}	1.890	**4.543**^{b}
[-3, -1]	1.235	**1.946**^{b}	1.956	1.172	1.534	**5.532**^{a}	1.454	**7.076**^{a}	1.538	**3.498**^{a}	**1.412**^{d}	1.967	**4.158**^{a}	1.339	**4.043**^{b}
[1, 3]	1.493	2.219	2.232	1.987	2.138	**4.094**^{b}	2.308	4.240	2.234	3.240	2.177	2.487	**3.547**^{b}	1.715	2.601
[1, 4]	1.651	**2.608**^{b}	2.992	1.922	2.463	4.346	2.604	4.727	2.576	3.811	2.560	2.629	**4.382**^{a}	3.267	3.285
[1, 5]	1.835	**2.724**^{b}	3.582	2.508	2.502	**4.795**^{b}	2.599	4.961	2.599	**4.263**^{a}	2.549	2.793	**4.943**^{a}	4.124	3.420

Panel B: Soybean Futures

Time Window	SampleN	SampleR	N85	R85	Sample7	Sample97	Sample0	Sample100	S	L	SS	M	LL	N(-85)	D
[-5, -1]	2.841	3.011	3.672	3.357	2.751	**5.667**^{b}	2.955	5.586	2.688	**4.036**^{b}	2.955	2.530	**4.574**^{a}	3.595	3.822
[-4, -1]	2.692	2.421	3.640	2.501	2.333	4.126	2.520	3.896	2.283	**3.184**^{b}	2.520	2.191	3.484	3.293	2.883
[-3, -1]	2.397	1.710	3.424	2.163	1.940	3.281	2.019	2.723	1.942	2.651	2.019	2.108	2.733	3.100	2.222
[1, 3]	2.403	**3.094**^{b}	1.808	2.287	2.822	4.434	2.824	5.238	2.780	3.686	2.824	3.093	3.751	1.964	**4.187**^{b}
[1, 4]	2.512	3.059	2.813	3.071	3.093	5.028	2.932	5.586	3.064	4.015	2.932	3.586	4.043	3.049	4.169
[1, 5]	2.776	**3.687**^{b}	3.679	3.737	3.490	5.063	3.449	5.425	3.479	4.349	3.449	4.045	4.205	4.020	4.586

^{a}: the volatility of the Sample is significantly greater than that of the benchmark Sample at the 0.01 level of significance. ^{b}: the volatility of the Sample is significantly greater than that of the benchmark Sample at the 0.05 level of significance.

Table 6a: Comparison of Volatility of Different Sample Sets (Set 1, Set 2 and Set 3) Using the t-Tests with Four Measures of Volatility

This table reports t test results for the null hypothesis that price limits do not affect the price volatility of futures contracts. Set 1: all days in which neither the day itself nor the previous day are limit hit days. Set 2: all days which are limit hit days. Set 3: all days in which the previous day was a limit hit day but the day itself is not a limit hit day. All Kim and Rhee's estimates are multiplied by 10000 in the table.

Panel A: Corn Futures

Measure of Volatility

Classical		Kim & Rhee		Parkinson		Garman & Klass	
Set1	Set2	Set1	Set2	Set1	Set2	Set1	Set2
7.557	**108.678**[a]	1.249	**11.515**[a]	5.180	**31.943**[a]	5.036	**27.508**[a]
Set1	Set3	Set1	Set3	Set1	Set3	Set1	Set3
7.557	**25.056**[a]	1.249	**2.716**[a]	5.180	**23.039**[a]	5.036	**24.443**[a]
Set3	Set2	Set3	Set2	Set3	Set2	Set3	Set2
25.056	**108.678**[a]	2.716	**11.515**[a]	23.039	**31.943**[b]	24.443	27.508

Panel B: Soybean Futures

Measure of Volatility

Classical		Kim & Rhee		Parkinson		Garman & Klass	
Set1	Set2	Set1	Set2	Set1	Set2	Set1	Set2
58.142	**916.634**[a]	1.389	**15.449**[a]	41.382	**239.940**[a]	39.990	**193.318**[a]
Set1	Set3	Set1	Set3	Set1	Set3	Set1	Set3
58.142	**189.056**[a]	1.389	**3.116**[a]	41.382	**181.036**[a]	39.990	**184.951**[a]
Set3	Set2	Set3	Set2	Set3	Set2	Set3	Set2
189.056	**916.634**[a]	3.116	**15.449**[a]	181.036	**239.940**[b]	184.951	193.318

[a]: the volatility of the set is significantly greater than that of the benchmark set at the 0.01 level of significance. [b]: the volatility of the set is significantly greater than that of the benchmark set at the 0.05 level of significance.

Table 6b: Comparison of Volatility of Different Sample Sets (Set 1, Set 2 and Set 3) Using the Wilcoxon Signed-Rank Tests with Four Measures of Volatility

This table reports Wilcoxon Signed-Rank Test results for the null hypothesis that price limits do not affect the price volatility of futures contracts. Set 1: all days in which neither the day itself nor the previous day are limit hit days. Set 2: all days which are limit hit days. Set 3: all days in which the previous day was a limit hit day but the day itself is not a limit hit day. All Kim and Rhee's estimates are multiplied by 10000 in the table.

Panel A: Corn Futures

Measure of Volatility

Classical		Kim & Rhee		Parkinson		Garman & Klass	
Set1	Set2	Set1	Set2	Set1	Set2	Set1	Set2
7.557	**108.678**[a]	1.249	**11.515**[a]	5.180	**31.943**[a]	5.036	**27.508**[a]
Set1	Set3	Set1	Set3	Set1	Set3	Set1	Set3
7.557	**25.056**[a]	1.249	**2.716**[b]	5.180	**23.039**[a]	5.036	**24.443**[a]
Set3	Set2	Set3	Set2	Set3	Set2	Set3	Set2
25.056	**108.678**[a]	2.716	**11.515**[a]	23.039	**31.943**[a]	24.443	**27.508**[b]

Panel B: Soybean Futures

Measure of Volatility

Classical		Kim & Rhee		Parkinson		Garman & Klass	
Set1	Set2	Set1	Set2	Set1	Set2	Set1	Set2
58.070	**916.634**[a]	1.387	**15.449**[a]	41.336	**239.940**[a]	39.945	**193.318**[a]
Set1	Set3	Set1	Set3	Set1	Set3	Set1	Set3
58.070	**189.056**[a]	1.387	**3.116**[a]	41.336	**181.036**[a]	39.945	**184.951**[a]
Set3	Set2	Set3	Set2	Set3	Set2	Set3	Set2
189.056	**916.634**[a]	3.116	**15.449**[a]	181.036	239.940	184.951	193.318

[a]: the volatility of the set is significantly greater than that of the benchmark set at the 0.01 level of significance. [b]: the volatility of the set is significantly greater than that of the benchmark set at the 0.05 level of significance.

Table 6c: Comparison of Volatility of Different Sample Sets (Set 2, Set 3 and Set 4) Using the t-Tests with Four Measures of Volatility

This table reports t test results on the null hypothesis that price limits do not affect the price volatility of futures contracts. Set 2: all days which are limit hit days. Set 3: all days in which the previous day was a limit hit day but the day itself is not a limit hit day. Set 4: all days before a limit hit when the previous day was not a limit hit. All Kim and Rhee's estimates are multiplied by 10000 in the table.

Panel A: Corn Futures

Measure of Volatility

Classical		Kim & Rhee		Parkinson		Garman & Klass	
Set3	Set2	Set3	Set2	Set3	Set2	Set3	Set2
25.056	**108.678**[a]	2.716	**11.515**[a]	23.039	**31.943**[a]	24.443	**27.508**[c]
Set4	Set2	Set4	Set2	Set4	Set2	Set4	Set2
13.688	**108.678**[a]	1.643	**11.515**[a]	11.715	**31.943**[a]	11.992	**27.508**[a]
Set4	Set3	Set4	Set3	Set4	Set3	Set4	Set3
13.688	**25.056**[b]	1.643	**2.716**[b]	11.715	**23.039**[b]	11.992	**24.443**[b]

Panel B: Soybean Futures

Measure of Volatility

Classical		Kim & Rhee		Parkinson		Garman & Klass	
Set3	Set2	Set3	Set2	Set3	Set2	Set3	Set2
189.056	**916.634**[a]	3.116	**15.449**[a]	181.036	**239.940**[b]	184.951	193.318
Set4	Set2	Set4	Set2	Set4	Set2	Set4	Set2
131.596	**916.634**[a]	2.164	**15.449**[a]	106.989	**239.940**[a]	99.006	**193.318**[a]
Set4	Set3	Set4	Set3	Set4	Set3	Set4	Set3
131.596	189.056	2.164	**3.116**[c]	106.989	**181.036**[a]	99.006	**184.951**[a]

[a]: the volatility of the set is significantly greater than that of the benchmark set at the 0.01 level of significance. [b]: the volatility of the set is significantly greater than that of the benchmark set at the 0.05 level of significance. [c]: the volatility of the set is significantly greater than that of the benchmark set at the 0.10 level of significance.

Table 6d: Comparison of Volatility of Different Sample Sets (Set 2, Set 3 and Set 4) Using the Wilcoxon Signed-Rank Tests with Four Measures of Volatility

This table reports Wilcoxon Signed-Rank Test results for the null hypothesis that price limits do not affect the price volatility of futures contracts. Set 2: all days which are limit hit days. Set 3: all days in which the previous day was a limit hit day but the day itself is not a limit hit day. Set 4: all days before a limit hit when the previous day was not a limit hit. All Kim and Rhee's estimates are multiplied by 10000 in the table.

Panel A: Corn Futures

Measure of Volatility							
Classical		Kim & Rhee		Parkinson		Garman & Klass	
Set3	Set2	Set3	Set2	Set3	Set2	Set3	Set2
25.056	**108.678**[a]	2.716	**11.515**[a]	23.039	**31.943**[a]	24.443	**27.508**[a]
Set4	Set2	Set4	Set2	Set4	Set2	Set4	Set2
13.688	**108.678**[a]	1.643	**11.515**[a]	11.715	**31.943**[a]	11.992	**27.508**[a]
Set4	Set3	Set4	Set3	Set4	Set3	Set4	Set3
13.688	**25.056**[a]	1.643	**2.716**[a]	11.715	**23.039**[a]	11.992	**24.443**[a]

Panel B: Soybean Futures

Measure of Volatility							
Classical		Kim & Rhee		Parkinson		Garman & Klass	
Set3	Set2	Set3	Set2	Set3	Set2	Set3	Set2
189.056	**916.634**[a]	3.116	**15.449**[a]	181.036	**239.940**[a]	184.951	193.318
Set4	Set2	Set4	Set2	Set4	Set2	Set4	Set2
131.596	**916.634**[a]	2.164	**15.449**[a]	106.989	**239.940**[a]	99.006	**193.318**[a]
Set4	Set3	Set4	Set3	Set4	Set3	Set4	Set3
131.596	**189.056**[e]	2.164	**3.116**[e]	106.989	**181.036**[a]	99.006	**184.951**[a]

[a]: the volatility of the set is significantly greater than that of the benchmark set at the 0.01 level of significance. [b]: the volatility of the set is significantly greater than that of the benchmark set at the 0.05 level of significance. [e]: the volatility of the set is significantly greater than that of the benchmark set at the 0.10 level of significance.

Table 7a: Comparison of Volatility of Twelve Sample Sets of Corn Futures Which Have Different Nlimit/Ntotal Values Using the Four Measures of Volatility

This table reports Wilcoxon Signed-Rank Test results for the null hypothesis that price limits do not affect the price volatility of futures contracts. Nlimit/Ntotal is defined as the number of minutes the futures contract trading is constrained by its limit price (Nlimit) over the total minutes of the trading day (Ntotal). All limit hit occurrences are divided into 12 sets according to Nlimit/Ntotal values. Set (1/12) has the smallest Nlimit/Ntotal and is the least constrained set while set (12/12) has the largest Nlimit/Ntotal and is the most constrained set. Daily volatility of set (n/12) is compared with benchmark set ((n-1)/12) which is less constrained from 1 day after a limit-hit to 3 days after the limit-hit for corn futures. Daily volatility is calculated using four measures: 1) classical volatility estimate, 2) Parkinson's (1980) estimate based on daily high and low prices, 3) Garman and Klass's (1980) estimate of volatility, and 4) Kim and Rhee's (1997) estimate of volatility. All Kim and Rhee's estimates are multiplied by 10000 in the table.

		Corn Futures											
Measure of Volatility	Day	Set(1/12)	Set(2/12)	Set(3/12)	Set(4/12)	Set(5/12)	Set(6/12)	Set(7/12)	Set(8/12)	Set(9/12)	Set(10/12)	Set(11/12)	Set(12/12)
Classical	t=0	64.163	44.956	66.113	146.050	55.513	90.363	90.206	115.488	124.563	193.638	161.313	139.975
	t=1	25.750	31.819	39.194	48.088	**10.131****	32.563	13.113	**53.975**^{b}	81.144	92.538	123.325	92.663
	t=2	48.556	26.725	**49.538**^{c}	**79.088**^{b}	32.675	46.981	14.325	**70.956**^{b}	35.244	**79.094**^{c}	94.344	67.450
	t=3	40.381	48.600	66.188	46.463	**6.944*****	**34.831**^{c}	19.738	**68.213**^{c}	68.744	72.256	94.513	60.619
Kim&Rhee	t=0	7.848	7.341	7.326	14.258	8.672	12.731	10.763	9.877	13.219	17.392	11.330	13.728
	t=1	1.757	**4.065**^{c}	4.415	5.123	**1.470***	3.628	1.276	**4.128**^{c}	6.469	5.843	8.105	9.504
	t=2	3.862	3.539	**5.087**^{c}	**8.639**^{c}	4.758	3.928	1.606	**5.266**^{b}	3.332	5.154	7.089	5.779
	t=3	2.855	4.879	4.605	3.488	**1.217****	3.669	2.444	5.224	6.208	5.706	6.018	5.521
Parkinson	t=0	52.401	33.015	25.344	57.942	23.324	37.623	14.447	59.847	43.188	19.483	19.702	0.000
	t=1	21.298	15.329	12.222	**29.810**^{c}	**8.395*****	15.901	10.164	**40.134**^{a}	35.384	67.818	43.267	59.944
	t=2	11.181	14.878	25.452	10.437	12.033	26.343	19.386	**38.317**^{b}	47.861	38.951	70.618	**20.274*****
	t=3	13.841	8.719	14.564	**31.935**^{c}	**7.225****	**14.411**^{b}	17.412	**40.716**^{c}	25.290	64.948	35.310	49.656

	t=0	53.120	40.101	21.813	42.730	23.801	37.604	11.976	36.950	25.169	14.616	12.512	0.000
Garman&Klass	t=1	20.476	18.146	10.190	**24.160^c**	**10.715****	16.331	13.322	**41.755^b**	38.996	78.814	41.029	52.629
	t=2	11.331	13.815	15.698	11.068	11.142	21.108	22.487	31.134	45.088	38.585	66.292	**24.249****
	t=3	12.780	7.743	11.520	**30.976^c**	**8.171****	14.674	17.381	23.379	25.613	46.620	28.073	57.723

[a]: the volatility of set (n/12) is significantly greater than that of the benchmark set ((n-1)/12) at the 0.01 level of significance. [b]: the volatility of set (n/12) is significantly greater than that of the benchmark set ((n-1)/12) at the 0.05 level of significance. [c]: the volatility of set set (n/12) is significantly greater than that of the benchmark set ((n-1)/12) at the 0.10 level of significance. ***: the volatility of set set (n/12) is significantly less than that of the benchmark set ((n-1)/12) at the 0.01 level of significance. **: the volatility of set (n/12) is significantly less than that of the benchmark set ((n-1)/12) at the 0.05 level of significance. *: the volatility of set (n/12) is significantly less than that of the benchmark set ((n-1)/12) at the 0.10 level of significance.

Table 7b: Comparison of Volatility of Eight Sample Sets of Soybean Futures Which Have Different Nlimit/Ntotal Values Using the Four Measures of Volatility

This table reports Wilcoxon Signed-Rank Test results for the null hypothesis that price limits do not affect the price volatility of futures contracts. Nlimit/Ntotal is defined as the number of minutes the futures contract trading is constrained by its limit price (Nlimit) over the total minutes of the trading day (Ntotal). All limit hit occurrences are divided into 8 sets according to Nlimit/Ntotal values. Set (1/8) has the smallest Nlimit/Ntotal and is the least constrained set while set (8/8) has the largest Nlimit/Ntotal and is the most constrained set. Daily volatility of set (n/8) is compared with benchmark set ((n-1)/8) which is less constrained from 1 days after limit-hit to 3 days after limit-hit for soybean futures. Daily volatility is calculated using four measures: 1) classical volatility estimate, 2) Parkinson's (1980) estimate based on daily high and low prices, 3) Garman and Klass's (1980) estimate of volatility, and 4) Kim and Rhee's (1997) estimate of volatility. All Kim and Rhee's estimates are multiplied by 10000 in the table.

		Soybesan Futures							
Measure of Volatility	Day	Set(1/8)	Set(2/8)	Set(3/8)	Set(4/8)	Set(5/8)	Set(6/8)	Set(7/8)	Set(8/8)
Classical	t=0	469.15	618.988	634.081	973.488	799.8	1165.256	900.256	1138.925
	t=1	187.8	256.4	416.063	**31.869*****	**317.881^b**	376.238	**387.038^c**	597.731
	t=2	261	236.256	**472.938^c**	309.463	293.638	**868.681^b**	**283.006****	650.456
	t=3	332.525	362.581	293.544	150.406	**445.406^b**	310.675	278.425	478.281
Kim&Rhee	t=0	8.351	12.664	11.668	17.985	13.702	14.693	15.802	16.19
	t=1	3.103	3.83	**6.350^c**	**0.638*****	**4.146^b**	4.492	**7.434^b**	7.496
	t=2	3.701	3.419	**6.041^c**	5.397	3.609	**10.746^a**	**4.462****	7.462
	t=3	5.277	5.434	3.699	2.78	5.602	4.094	4.189	5.675
Parkinson	t=0	557.859	286.244	238.254	200.115	164.384	387.091	45.019	3.077
	t=1	160.68	135.217	147.531	85.559	178.849	248.225	163.036	225.583
	t=2	148.302	184.917	173.782	**57.721***	189.203	214.955	201.468	215.809
	t=3	167.517	95.606	223.307	127.888	145.462	**255.738^c**	**103.883****	**238.045^c**

Garman&Klass	t=0	549.012	271.048	214.982	99.683	115.511	225.671	31.846	3.335
	t=1	188.171	110.4	130.619	102.881	154.662	296.222	145.907	153.779
	t=2	149.059	221.583	137.23	**55.394***	159.553	131.725	184.655	192.797
	t=3	153.402	99.127	199.583	105.503	**152.855**^{c}	**240.194**^{b}	**73.806*****	**223.754**^{b}

^{a}: the volatility of set (n/8) is significantly greater than that of the benchmark set ((n-1)/8) at the 0.01 level of significance. ^{b}: the volatility of set (n/8) is significantly greater than that of the benchmark set ((n-1)/8) at the 0.05 level of significance. ^{c}: the volatility of set set (n/8) is significantly greater than that of the benchmark set ((n-1)/8) at the 0.10 level of significance. ***: the volatility of set set (n/8) is significantly less than that of the benchmark set ((n-1)/8) at the 0.01 level of significance. **: the volatility of set (n/8) is significantly less than that of the benchmark set ((n-1)/8) at the 0.05 level of significance. *: the volatility of set (n/8) is significantly less than that of the benchmark set ((n-1)/8) at the 0.10 level of significance.