The Effect of Nuclear Disasters on Energy Futures Markets

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This is to certify that the thesis prepared

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complies with the regulations of the University and meets the accepted standards with respect to originality and quality.

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Abstract

The Effect of Nuclear Disasters on Energy Futures Markets

In my thesis, I aim to examine the effect of nuclear disasters on energy futures markets. I use the crude oil and the heating oil futures contracts, which are the two most actively traded energy futures contracts, as representatives of this market. The nuclear disasters are classified into three categories, the incident-level category, which includes events rated level 1 to level 3, the accident-level category, which includes events rated level 4 to level 7 and the total category, which includes both incident-level and accident level events. In my thesis, I address the effect of all three categories of nuclear events upon both crude oil futures and heating oil futures contracts, to determine whether the nuclear events affect the energy futures market and if so, whether the impacts are related to the severity of the nuclear disasters. For both contracts, I use the market model with Generalized Autoregressive Conditional Heteroskedastic (GARCH) effects to estimate the distribution of returns in the estimation period which includes no nuclear disasters. The results show that for both contracts, the accident-level category of events are associated with statistically significant negative impacts for almost each day in the event window and post-event window. However, for the incident-level and the total category of events, the cumulative average abnormal returns are only statistically significant negative for the first 2 days following the event day and the last 10 days in the post-event window. The cumulative average abnormal returns show that only the accident-level category has a persistent impact upon the futures contracts beyond the event date. I also find that the heating oil futures contract adjusts faster to information about the nuclear disaster, since during the post-event window, the cumulative average abnormal returns revert to a zero mean.

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1. Introduction

A nuclear disaster, as defined by the International Atomic Energy Agency (IAEA), is an event that could cause significant problems to the facility that houses the nuclear reactor, to the environment and also to the safety of people. The International Atomic Energy Agency (IAEA) introduced the International Nuclear and Radiological Event Scale (INES) in 1990 which is intended to describe the level of the severity of the disaster. The INES divided the nuclear disasters into 7 nonzero levels and a level 0. Level 0 is the deviation which has no safety significance, level 1 is anomaly which will affect the defence in depth, level 2 is the incident which will not only affect the people but also the environment but not to a large extent, level 3 is the serious incident which the influences are much stronger than level2, level 4 is accident with local consequences, level 5 is accident with wider consequences, level 6 is serious accident which will cause the release of radioactive material, t level 7 is major accident which will make a significant damage to the environment and people. Also on the INES scale, level 1 to level 3 is defined as incident-level and level 4 to level 7 is defined as accident-level. The more detailed description of classification is showed in **Table 1.1**.

Table 1.1: The Description of INES

Category	Level	Description
	0	Deviation (No Safety Significance)
Incident	1	Anomaly
	2	Incident
	3	Serious Incident
Accident	4	Accident with Local Consequences

5	Accident with wider Consequences
6	Serious accident
7	Major Accident

In my thesis, I address the effect of the nuclear event upon energy futures markets, while testing all the nuclear events by using the incident category (level 1 to level 3), the accident category (level 4 to level 7) and a total category which includes both incident category and accident category. I do not test the effect of level 0 events because level 0 is deviation.

Nuclear disasters may directly affect the energy markets, including both energy-based stocks and energy futures contracts, since nuclear reactors are a source of energy. The energy futures market includes the crude oil, heating oil, natural gas, and gasoline futures contracts, as well as other markets. In my paper, I focus on the crude oil and heating oil futures contracts, because they are the top two most active futures contracts, on the basis of trading volume, and hence may be deemed representative of the energy futures market.

In the finance literature, a number of papers have studied the effect of nuclear disasters on energy-based stocks. For example, Hill and Schneeweis (1983) studied the effect of the Three Mile Island (TMI) nuclear disaster on electric utility stock prices. They found that there was an immediate impact of the TMI on these stock prices. More specifically, by using the two-index market model, they found that the impact of the TMI on nuclear-energy based firms was more than that on non-nuclear-energy based firms. Fields and Janjigian (1989) did a similar study but for the Chernobyl nuclear disaster, and obtained similar results, namely, that the shareholders earned significant negative abnormal returns in the following 20 days after the event. Ferstl, Utz and Wimmer (2012) studied the effect of the Japanese Fukushima-Daiichi nuclear disaster on energy stocks markets in four different countries by using the event study methodology. The results showed significant abnormal returns during the one-week event window and the following four- week post event window.

However, it is hard to find papers that examined how the nuclear disasters affected the energy futures markets, including both the crude oil futures contract and the heating oil futures contract. Most event studies of oil futures markets usually focused on events such as the Organisation of Petroleum Exporting Countries (OPEC) announcements and the Strategic Petroleum Reserve (SPR) announcements. Unlike the above events, which occur regularly, nuclear disasters do not follow a regularly occurring schedule, but over the course of history, many nuclear disasters have occurred. On March 11, 2011, the Japanese Fukushima-Daiichi nuclear accident, which was categorized as the highest level, level 7, had a serious impact in many aspects upon the whole world. This thesis therefore addresses a gap in the literature by addressing the impact of nuclear disasters on the energy futures markets. In addition, in my thesis, I also test the relationship between the severity of the nuclear event and the impact. This study has implications for the pricing of the energy futures markets, when nuclear disasters or other unexpected events were to occur in the future.

In my thesis, I examine the effect of nuclear events over the period March 1983 to August 2017 on the crude oil and the heating oil futures contracts separately, using the event study methodology. A long period is chosen to contain as many events as possible. A total of 30 events for the crude oil futures contract including 25 incident-level and 5 accident-level events, and a total of 27 events for the heating oil futures contract including 24 incident-level and 3 accident-level events are examined in this thesis.

In the following sections, I detail the literature review, the data, the methodology and the results of my analysis.

2. Literature review

The main method I use in this thesis is the event study methodology. The event study was first introduced by Fama, Fisher, Jensen and Roll (FFJR) (1969). They examined the adjustment of stock prices to new information. More specifically, they tried to find whether or not stock splits affect stock prices, and if they do, to what extent the abnormal returns can be explained. They used monthly data on stock returns from 1926 to 1960 and used a market model to model normal returns in the absence of a stock split. FFJR defined the split month as month 0 and the period from 29 months before the announcement of the split and 30 months after the announcement as the event period. They found that stock splits are often accompanied by increases in the dividend, which implies that investors could incorporate the change in the dividend and re-valuate the expected return on the stock. They also found that the stock price adjusts very rapidly to the information of the stock split which supports the hypothesis that the market is efficient. This was the first time that an event study methodology was used. Since then, the event study methodology has been widely used to study various aspects of the stock market.

2.1 Event Studies of Stock Markets

Brown and Warner (1980) examined the different models used in event studies conducted by using monthly stock returns. They tested three models, the Mean Adjusted Returns model, the Market Adjusted Returns model and the Market and Risk Adjusted Returns model, and assessed the probability of committing Type 1 errors – rejecting the null hypothesis of no abnormal performance when it is true and Type 2 errors – failing to reject the null hypothesis of no abnormal performance when it is false. They found that when they select the stocks and events randomly and also the event dates of different stocks in the no clustering case, the differences between the abnormal returns of the three models were quite small. For the calendar time clustering case, under the same conditions, they found that the Mean Adjusted Returns model performed very poorly compared to the other two models. In addition, they also tested the one-factor market model, the two-factor model with Fama MacBeth residuals and the Control Portfolio model and found that when there was systematic risk clustering rather than calendar time clustering of the events, the Control Portfolio model performed poorer than the other two models. Even the Mean Adjusted model performed better than the Control Portfolio model under these conditions. Brown and Warner (1985) examined that how the use o daily stock returns affected the results of the event study methodology. They investigated three problems: 1) the non-normality of returns and abnormal returns; 2) the bias in ordinary least squares (OLS) estimates of market model parameters and; 3) estimation of the variance in the hypothesis test. By using daily stock returns, they reinforced the results of their 1980 paper based on monthly data, which was that the methodologies based on the OLS market model and the standard parametric tests were well-specified under a variety of conditions.

Binder (1998) discussed several aspects of the event study methodology-- the tests of the hypothesis, the different benchmarks and the power of the methodology. In his paper, he tested a multiple regression model which estimated the abnormal return as the coefficient of a dummy variable which would have a value of 1 in the event period and 0 otherwise. He noted that when the market model is used, the actual return on the stock is regressed on the market return in the estimation period, to determine the expected return as a function of the market return. In the event period, the abnormal return is estimated by the difference between the actual return and the expected return, which is estimated using the coefficients of the regression and the actual market return in the event period. However, we could also estimate the abnormal return by extending the sample period to contain the event window, and regressing the actual return on the market return and a dummy variable which equals 1 in the event period and 0 otherwise, when there is only one event. Binder argued that this regression model could also be used when there were multiple events, in which case, the coefficient of the dummy variable would represent the average abnormal return among all of the events. In addition, in the regression framework, the model of the normal returns could also be extended. For example, the CAPM model could be used rather than the market model.

2.2 Event Studies of Futures Markets

While event studies of futures markets suffer from the difficulty of estimating abnormal returns and choosing the appropriate model to generate the normal returns, event studies have been conducted on futures markets. Deaves and Krinsky (1992) studied the behavior of oil futures returns around OPEC conferences. They used returns on the nearby crude oil and heating oil futures contracts. They used an autoregressive conditional heteroscedastic (ARCH) model to estimate normal returns. The advantage of the ARCH methodology is that it can address volatility clustering. Deaves and Krinsky found that, over the 1980s, in comparison to excess returns usually found in the equity markets, the excess returns in the futures markets were large following the OPEC conferences classified as “good news” conferences. In addition, as the cumulative abnormal returns persisted even for 20 days after the event, illuminating that the market was not efficient.

Miclăuş, Lupu, Dumitrescu and Bobircă (2008) used the event study methodology to examine the effect of National Allocation Plan announcements on daily carbon futures returns in Europe. First, they used all futures contracts which expired in 2007 and collected daily closing prices for the contracts during this period. They divided the selected announcements into two categories, of which the first category contained 6 types of announcements while the second category contained 2 types of announcements. They used the AR (1)-GARCH (1, 1) model to estimate normal returns using an estimation period of 100 days before the event window. The event window was from 10 days before to 10 days after the announcement day. Then the cumulative abnormal returns were calculated by summing the abnormal returns in the event window. The results showed that the cumulative abnormal returns for all announcements were not statistically significant which implied that market participants had taken the effect of the National Allocation Plan into account into expected futures prices and therefore could more accurately predict future price movements.

Mckenzie, Thomsen and Dixon (2004) examined the different models of event study methodology on commodity futures daily returns. In their paper, the constant mean return (CMR) model, and the regression-based models including the OLS model, and the GARCH type models, were examined separately. Simulations of futures returns using the models were conducted for agricultural futures contracts on corn, soybeans, live cattle and hogs. Within the simulations, they used different number of observations in the estimation period used to calculate normal returns and included 20, 40, 60 and 100 events separately. They found that for the short estimation period, the CMR models did not perform very well. While the OLS and GARCH models performed similarly in terms of the size, GARCH type models were more powerful. The more powerful of the statistical advantage is mainly explained by that the GARCH models could better solve the distributional problem inherent in the daily futures returns such as volatility clustering and excess kurtosis. Overall, in their paper, they suggested that for the event study using daily commodity futures returns, the GARCH type models would be the better choice.

Demirer and Kutan (2010) tested the behavior of daily crude oil spot and futures prices around OPEC and SPR announcements, using the event study methodology, using data over the period March 1983 to June 2008. They examined the nearest futures contract, the third-closest futures contract and the twelfth-closest futures contract. Demirer and Kutan regarded each official press release as an event. They separated the 63 OPEC events into three types: 17 announcements of an increase in production, 25 announcements of no change in production and 21 announcements of a decrease in production. Similarly, the 15 SPR announcements were divided into two types: 11 announcements of release of crude oil from the SPR and 4 announcements of an addition of crude oil to the SPR. They used the event study methodology for both the OPEC and SPR announcements. The normal return in the estimation period was determined by three separate models: the market model, the ARCH model and the Fama-French model. The estimation window extended from 80 days to 21 days before the event day. Using the parameters of the estimated normal return model, the abnormal return was calculated as the actual return minus the normal return for each day in the event window, which extended from 20 days before to 20 days after the event day. The average abnormal return was calculated for each day in the event window for each type of announcement, following which the cumulative average abnormal return was calculated by adding the average returns from day -20 to 5, 10, 15 and 20 days after the event day separately. They found that for all the three methods used to estimate normal returns, the impact of announcements of increases in OPEC production were not statistically significant. However, the impact of announcements of decreases in OPEC production was statistically significant. For the SPR announcements, the results of the tests showed that the cumulative abnormal returns were not statistically significant, indicating an efficient market reaction to the SPR announcements. Therefore, they suggested that the SPR announcements were a useful tool to stabilize the oil market because of inducing the efficient market.

3. Empirical Analysis and Results

3.1 Futures Market Data

I use daily settlement prices for the light crude oil futures contract over the period March 31, 1983 to August 18, 2017, and for the heating oil futures contract over the period June 3, 1986 to August 18, 2017, from DataStream. This period is long enough to contain as many nuclear events as possible. I use the continuous series constructed by using prices of the nearby futures contract and switching over to the next closest to maturity futures contract following the last trading day of the nearby futures contract. The reason why to use the data from nearby contract is that it is the most liquid. Then I calculate the daily returns for each futures contract as ln (p_t/p_{t-1}) *100 where p_t is the daily settlement price of the contract on day t.

Fig.3.1.1 shows the daily returns for the crude oil futures contract over the period March 31, 1983 to August 18, 2017, while **Fig.3.1.2** shows the daily returns for the heating oil futures contract over the period June 3, 1986 to August 18, 2017. The two figures indicate that the average daily returns of both contracts are around zero. **Fig.3.1.3** and **Fig.3.1.4** show the daily returns squared for both contracts. The two data series are exhibiting volatility clustering problems as high volatilities tend to be followed by high volatilities and low volatilities tend to be followed by low volatilities.

Fig. 3.1.1 Daily Returns for the Crude Oil Futures Contract

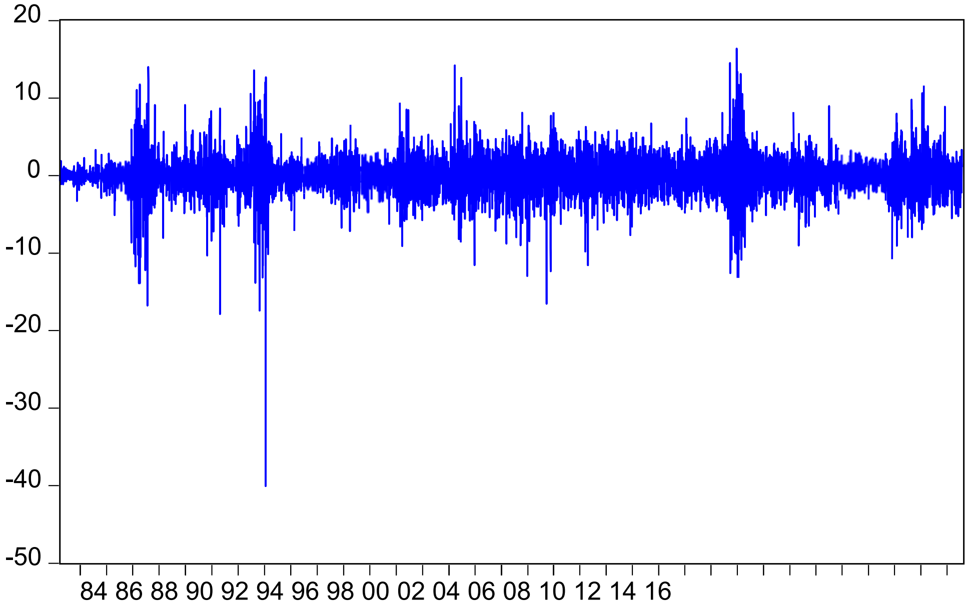


Fig. 3.1.2 Daily Returns for the Heating Oil Futures Contrat

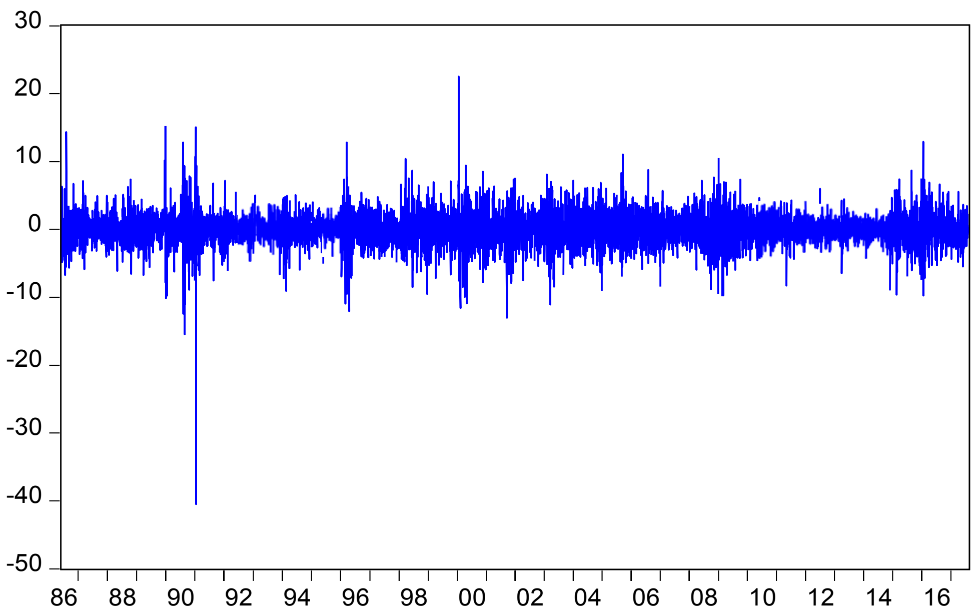


Fig. 3.1.3 Daily Returns Squared for the Crude Oil Futures Contract

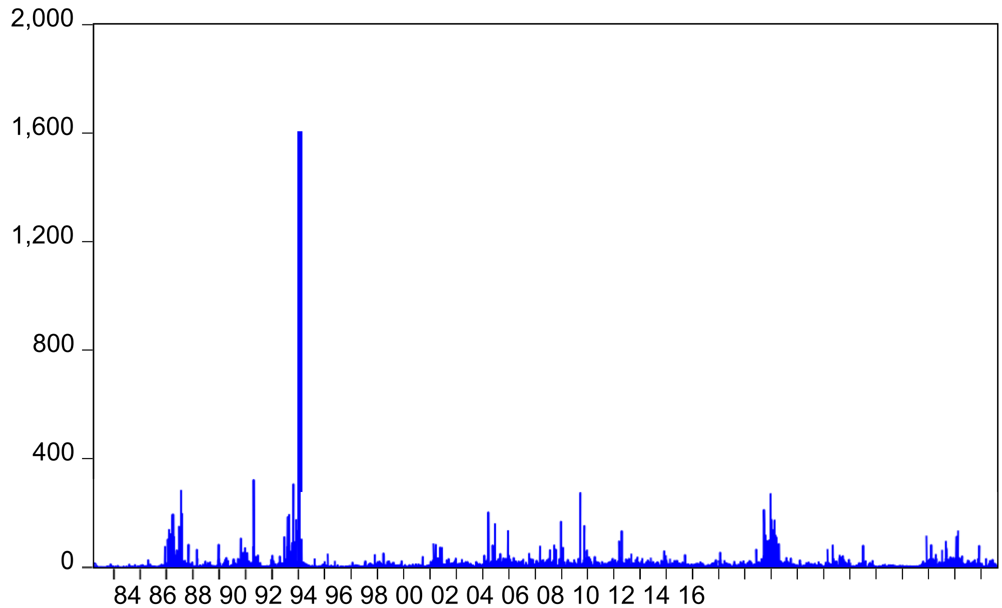


Fig. 3.1.4 Daily Returns Squared for the Heating Oil Futures Contract

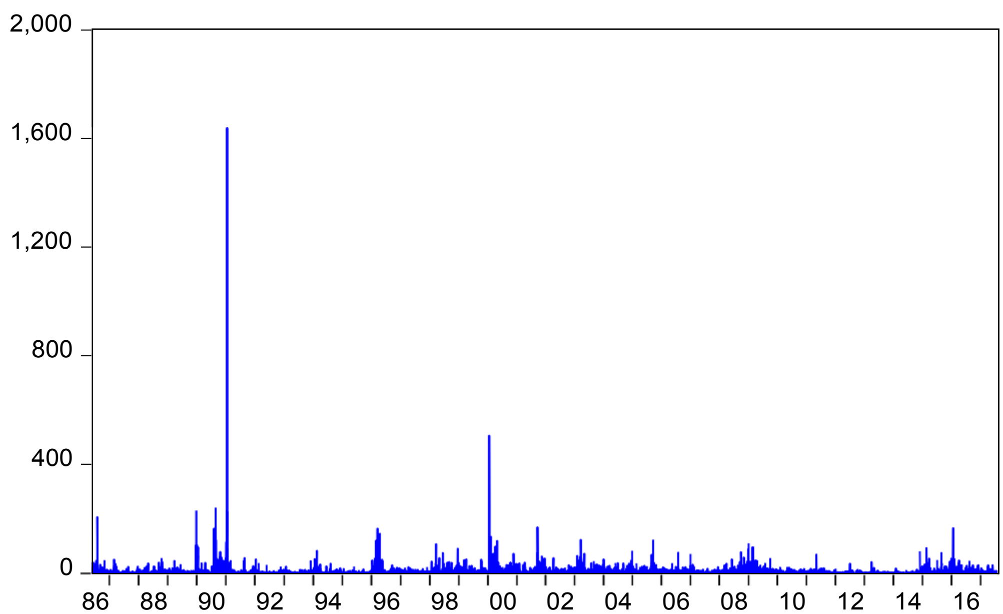


Table 3.1.1 presents the descriptive statistics of the daily returns for the crude oil and heating oil futures contracts. The skewness of daily returns for both contracts are negative, while the daily returns for both contracts exhibit excess kurtosis, which is greater than 3. The results indicate that both the data series are non-normal. The Jarque-Bera statistic also confirms the non-normality of the daily returns for both contracts.

TABLE 3.1.1 Summary Statistics for the Daily Returns on the Futures Contracts

Contract	Crude Oil	Heating Oil
Period of data	March 31, 1983 to August 18, 2017	June 3, 1986 to August 18, 2017
Number of Observations	8671.000	7870.000
Mean	0.005	0.016
Maximum	16.410	22.500
Minimum	-40.048	-40.468
Std. Dev.	2.381	2.349
Skewness	-0.732	-0.532
Kurtosis	17.618	18.284

Jarque-Bera statistic	77,977.530	76,968.970

3.2 Market Return

I obtain data on the daily Standard and Poor's 500 (S&P 500) stock market index from DataStream for the period March 31, 1983 through August 18, 2017 and calculate daily returns for the index, as is done for each futures contract. This is an estimate of the market return.

Fig.3.2.1 and **Fig.3.2.2** show that the daily returns on the S&P 500 stock index for the crude oil futures contract over the period March 31, 1983 to August 18, 2017 and the heating oil futures contract over the period June 3, 1986 to August 18, 2017. The results both show that the daily returns of S&P 500 index fluctuate around average zero.

Fig.3.2.1 Daily Returns on the S&P 500 Stock Index of the Crude Oil Futures Contract

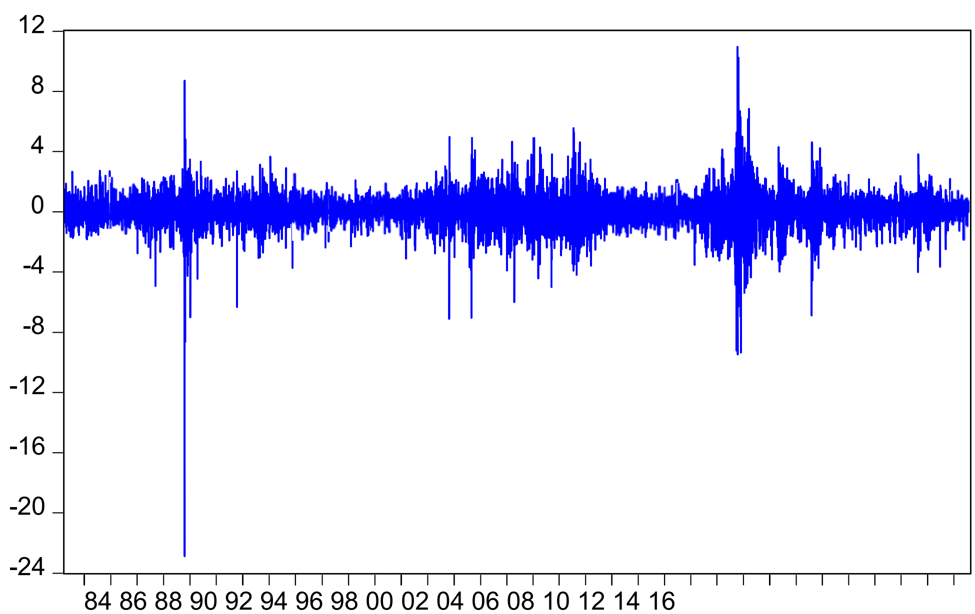
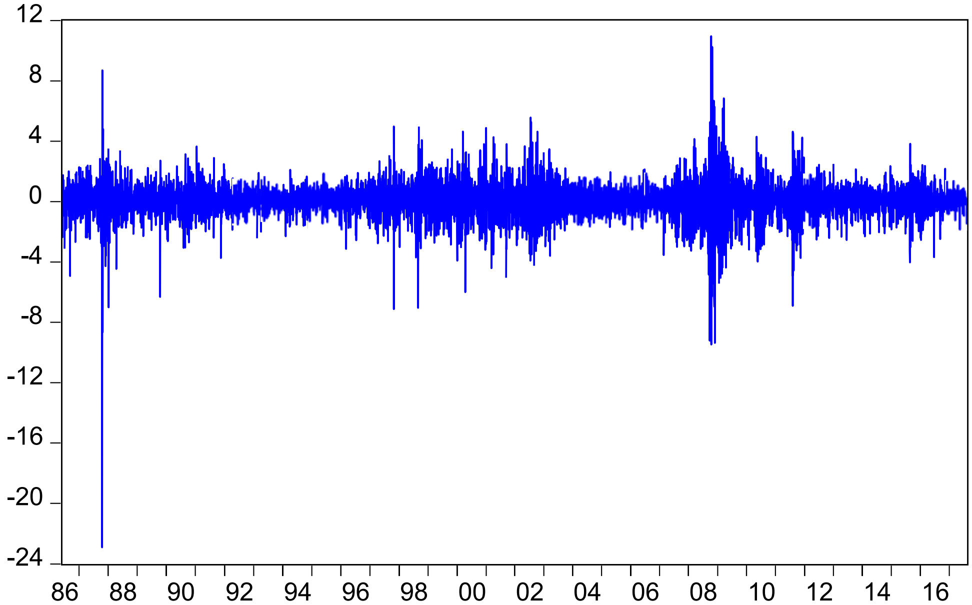


Fig.3.2.2 Daily Returns on the S&P 500 Stock Index of the Heating Oil Futures Contract



Then the **Fig.3.2.3** and **Fig.3.2.4** describe daily returns squared on the S&P 500 stock index for the crude oil futures contract and the heating oil futures contract. As the same as what I find in the daily returns squared of the two futures contracts, the daily returns squared of S&P 500 index for both contracts also show the volatility clustering problems.

Fig.3.2.3 Daily Returns Squared on the S&P 500 Stock Index of the Crude Oil Futures Contract

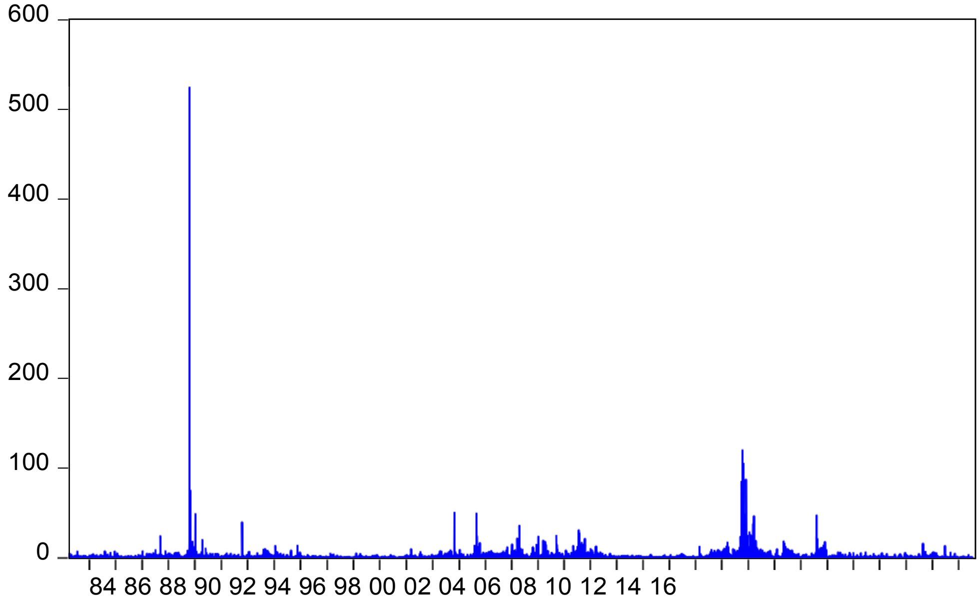


Fig.3.2.4 Daily Returns Squared on the S&P 500 Stock Index of the Heating Oil Futures Contract

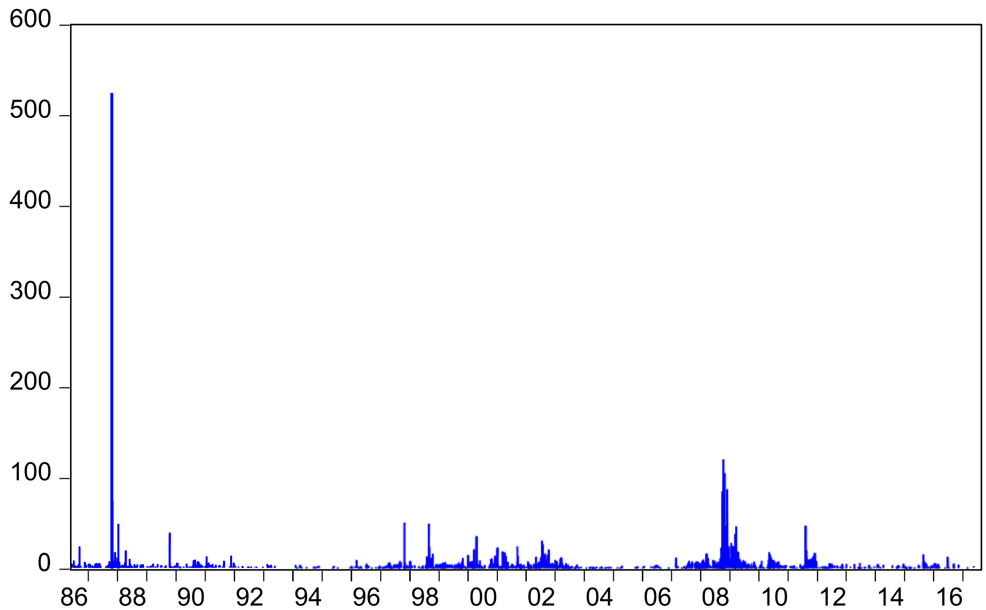


TABLE 3.2.1 Summary Statistics for the Daily Returns on the S&P 500 Stock Index

Corresponding Contract	S&P 500_Crude Oil	S&P 500_Heating Oil
Period of data	March 31, 1983 to August 18, 2017	June 3, 1986 to August 18, 2017

Number of Observations	8671.000	7870.000
Mean	0.032	0.029
Maximum	10.957	10.957
Minimum	-22.900	-22.900
Std. Dev.	1.119	1.150
Skewness	-1.251	-1.277
Kurtosis	31.432	31.010
Jarque-Bera statistic	294325.200	259403.500

3.3 Choice of Events, Event Window, Post-event Window and Estimation Period

Wheatley, Sovacool, and Sornette (2017) conducted a statistical study of 216 nuclear disasters over the period 1950 to 2014. They provide a new data set of nuclear incidents and accidents, and address their impact. They define an "event" that may cause financial damage, safety problems caused by radiation or human harm as a nuclear incident or accident. As mentioned in the introduction, according to INES (International Nuclear and Radiological Event Scale) introduced by the IAEA (The International Atomic Energy Agency), level 1 to level 3 are defined as the incidents and level 4 to level 7 are defined as the accidents. When choosing the events, they comply with the independent-event principle which means that the event which is triggered by another event will be regarded as the same event. Though this paper focuses most on the mathematic analysis of these nuclear events, the data set used here provides the newest and most comprehensive set of nuclear accidents and incidents. More specification, in their data set, they provided the date of the nuclear event happened, the location where nuclear events happened and the INES (International Nuclear and Radiological Event Scale) level of the nuclear events. Accordingly, I choose my sample of events from the nuclear events addressed by this paper. Since I need to test if the return on the futures contract is related to the severity of the event, I only include an event if its severity level is identified. In addition, in my thesis, I do not consider the events with a severity level of 0 since level zero is defined as deviation. Based on the data set providing by Wheatley, Sovacool, and Sornette (2017), the lists of the nuclear events examined in this thesis for the two futures contracts are showed as **Table 1** and **Table 2** in the Appendix.

I define the event day zero as the date on which the nuclear event actually happened. However, some events did not happen during business days, which means that no corresponding futures or stock index returns are available for these event days. For such events, I use the first business day following the event day for which the returns data are available as event day zero. As Ferstl, Utz and Wimmer (2012) note, nuclear disasters are not predicted or known events, hence, for the event window, I do not consider the days before the event day zero. I only contain the event day 0 and five business days after the event day zero, totally 6 business days in the event window to analyse the short-term effects of the nuclear disasters on both futures contracts. Then for post-event window, I use a period of 25 business days after the event window to examine the medium-term impacts of the nuclear disasters on the two futures contracts. I use a period of 35 business days before the event day zero from day -35 to day -1 as the estimation period. The reason why I choose the estimation period to be of this length is because some of the events occur on days which are close together. Some events also occur on the same day. Using 35 days for the estimation period allows me to include as many events as possible in the study. I drop some closely occurring events from the sample, following the rule that if the events have the same level of intensity, the one that occurred later is dropped, and if the events have different levels of intensity, the lower level of intensity event is dropped. **Table 3.3.1**, indicates that for the crude oil futures contract, 30 events are included in the sample, of which 5 events are at the accident-level, with levels ranging from 4 to 7 and 25 events are on the incident-level, with levels ranging from 1 to 3. For the heating oil futures contracts, totally 27 events are examined, of which 3 are at the accident-level and 24 are at the incident-level.

TABLE 3.3.1 Categories of Events Addressed for the Futures Contracts:

Categories	Crude Oil	Heating Oil
Total number of nuclear events	30	27
Accident-level events	5	3
Incident-level events	25	24

3.4 Model Used to Estimate Normal or Expected Returns in the Estimation Period

In this thesis, since I want to study the effects of multiple nuclear events and also examine the relationship between the severities of the nuclear disasters upon the two futures contracts, I choose to use the traditional event study methodology.

Let E (R_t) be the normal or expected return based on a model estimated using the estimation period extending from day -35 to day -1, where day 0 is the event date.

3.4.1 Market Model

In event studies of futures contracts, models used to estimate the normal or expected returns include the constant mean return model, the market model, the CAPM model, the ARCH model, etc. Cable and Holland (1999) did a pilot study about normal returns of four models (Market Model, Capital Asset Pricing Model, Market Adjusted Model and Mean Adjusted Returns Model) in event studies based on 30 UK quoted companies. All four models are nested within a general model, describing the parameter restrictions that are required to derive each individual model. The results showed that the regression-based model (ie Market Model, Capital Asset Pricing Model) performed better than the non-regression model (ie Market Adjusted Returns Model, Mean Adjusted Returns Model) in terms of the significance level. For regression based models, market model is acceptable simplification of the general model in all cases which is superior to CAPM (Capital Asset Pricing Model) model. Therefore, in my thesis, I use the market model which is also the most widely used model in event study. The market model is described as:

$$R_t = \alpha + \beta X_t + \varepsilon_t \qquad (1)$$

Where R_t is the daily return on the futures contract, X_t is the daily return on the S&P 500 index.

3.4.2 Market Model with GARCH Effects

Corhay and Rad (1996) applied the market model with GARCH effects to estimate expected returns in the estimation period in an event study. This adjustment led to more efficient estimators. Mckenzie, Thomsen and Dixon (2004) tested the performance of these models on commodity futures markets and concluded that the GARCH type models did better. Yang and Brorsen (1994) noted that GARCH type models can better accommodate the non-normality of daily futures returns which are also exhibited by the series of daily returns on the crude oil and heating oil futures contract. Therefore, in my thesis, I use the market model under GARCH effects to estimate the normal or expected returns in the estimation period. The market model under GARCH effects is described as:

$$R_t = \alpha + \beta X_t + \varepsilon_t \quad (2)$$

$$\varepsilon_t = e_t\sqrt{h_t} \quad e_{nt} \sim IN\ (0, 1) \quad (3)$$

$$h_t = w + \sum_{i=1}^{q} \mu_i \varepsilon_{t-i}^2 + \sum_{j=1}^{p} \gamma_j h_{t-j} \quad (4)$$

Where R_t is the daily return on the futures contract, α is the constant term, X_t is the daily return on the S&P 500 index, β is the coefficient of X_t, h_t describes the conditional variance of the return at time t. IN (0, 1) means the independent normal distribution with mean 0 and variance 1, $w > 0$, $\mu_i > 0$, $\gamma_j > 0$.

3.4.3 Market Model with GARCH Effects and T Distribution of the Error Terms

Wang, Fawson, Barrett and McDonald (2001) noted that the GARCH model with normally distributed errors can only partially address the thick tails exhibited by the distribution of the daily return series, but failed to sufficiently capture the kurtosis evident in the distribution of asset returns. Baillie and Mayers (1991) argued that the GARCH model with an assumed t distribution for the error terms was more useful to address the excess kurtosis exhibited by the daily returns on both the crude oil and heating oil futures contracts. The Student's t distribution of the error terms in the GARCH model was first suggested by Bollerslev (1987). The t distribution exhibits thicker tails than the normal distribution. Since the daily returns of both futures contracts addressed in my thesis exhibit excess kurtosis, accordingly, I use a GARCH model with a Student's t distribution of the error terms to estimate normal or expected returns in the estimation period. The market model with a GARCH (1, 1) specification and with a Student's t distribution for the error terms is described as:

$$R_t = \alpha + \beta X_t + \varepsilon_t \quad (5)$$

$$\varepsilon_t \sim td\ (0, h_t, v), \quad (6)$$

$$h_t = w + \mu\varepsilon_{t-1}^2 + \gamma h_{t-1} \quad (7)$$

Where R_t is the daily return on the futures , α is the constant term, X_t is the daily return on the S&P 500 stock index, β is the coefficient of X_t , ε_t is the error term that is assumed to follow a t distribution. $\varepsilon_t \sim td\ (0, h_t, v)$ indicates a Student's t distribution with mean 0, variance h_t and v degrees of freedom, $w > 0$, $\mu_i > 0$, $\gamma_j > 0$.

The results of GARCH (1, 1) model with a Student's t distribution for three categories of crude oil and heating oil futures contracts are listed as Table 3 and Table 4 in the Appendix.

3.5 Average Abnormal Returns and Cumulative Average Abnormal Returns for Each Day in the Event Window and Post-event Window

In the traditional event study methodology, the main idea is to examine the abnormal return in the event window and post-event window. The abnormal return on any day in the event window and post-event window is the difference between the actual return on that day and the normal return or expected return E (R_t) based on the model estimated using returns in the estimation period. It is defined as:

$AR_t = R - \mathrm{E}\,(R_t)$ (8)

Where R_t is the daily return on day t in event window and post-event window.

After estimating the parameters of the model for the normal or expected returns using the returns for the estimation period, abnormal returns are calculated using the above equation for each day in the event window and the post-event window, extending from day 0 to day 30.

Once the daily abnormal returns are calculated, then the average abnormal returns across the relevant n events are calculated as:

$AAR_t = \sum_{c=1}^{n} AR_{ct}$ / n (9)

n is the number of events in each category, equalling 30, 25 and 5 for the crude oil futures contract and 27, 24 and 3 for the heating oil futures contract, for total, incident-level and accident-level events, respectively.

Then the t statistic of average abnormal returns is calculated by:

T - Statistics of AAR_t = (AAR_t -0) /Standard deviation of AAR_t (10)

The standard deviation of AAR_t is calculated by:

Standard deviation of $AAR_t = \frac{1}{n} * \sqrt{(AR_{1,}) + V(AR_{2,}) + \cdots + V(AR_{n,t})}$ (11)

Where $AR_{n,}$ represents the abnormal return of n events in each category for two futures contracts on day t.

Based on Rob Reider (2009), the unconditional variance of the abnormal return of GARCH (1, 1) model is calculated by:

σ^2 = w / (1- μ -γ)

(12)

Where w is the intercept of the variance term, μ is the coefficient of ARCH term, γ is the coefficient of GARCH term.

Cumulative average abnormal returns are calculated by adding the average abnormal returns from day 0 to day t using the following equation:

$$CAAR_t = \sum_{i=0}^{t} AAR_t \qquad (13)$$

Where day t is from 0 to 30.

Similarly, the t statistic of average abnormal returns is calculated by:

T - Statistics of $CAAR_t$ = ($CAAR_t$ -0) /Standard deviation of $CAAR_t$ (14)

The standard deviation of $CAAR_t$ is calculated by:

Standard deviation of $CAAR$ = $\sqrt{t+1}$ * Standard deviation of AAR_t (15)

Where t represents the day in event window and post-event window from 0 to 30.

3.6 Hypotheses

I address two questions in the analysis of the cumulative average abnormal returns: 1) Does the nuclear event have an impact on the futures contract on day t and if so, is it statistically significantly positive or negative? 2) Does the nuclear event have a persistent effect upon the futures contract, and is so, is the effect short-term or medium-term in nature?

In this thesis, because the overlapping of the multiple events, the post-event window only contains 25 days for medium-term study to avoid the occurrence of overlapping. For the long-term effect, it is still need further study to resolve the problem of the overlapping of the multiple nuclear events.

First, for normal returns in the estimation period, I use the market model with a GARCH (1, 1) specification and with a Student's t distribution for the error terms mentioned before.

$$R_t = \alpha + \beta X_t + \varepsilon_t \tag{5}$$

$$\varepsilon_t \sim td\ (0, h_t, v), \tag{6}$$

$$h_t = w + \mu\varepsilon_{t-1}^2 + \gamma h_{t-1} \tag{7}$$

Where R_t is the daily return on the futures , α is the constant term, X_t is the daily return on the S&P 500 stock index, β is the coefficient of X_t , ε_t is the error term that is assumed to follow a t distribution. $\varepsilon_t \sim td\ (0, h_t, v)$ indicates a Student's t distribution with mean 0, variance h_t and v degrees of freedom, $w > 0$, $\mu_i > 0$, $\gamma_j > 0$.

Then the daily abnormal returns are calculated by:

$$AR_t = R - E\ (R_t) \tag{8}$$

Where R_t is the daily return on day t in the event window and post-event window.

After this, the average abnormal returns across the relevant n events are calculated as:

$AAR_t = \sum_{c=1}^{n} AR_{ct}$ / n (9)

n is the number of events in each category, equalling 30, 25 and 5 for the crude oil futures contract and 27, 24 and 3 for the heating oil futures contract, for total, incident-level and accident-level events, respectively.

Cumulative average abnormal returns are calculated by adding the average abnormal returns from day 1 to day T using the following equation:

$CAAR_t = \sum_{i=0}^{t} AAR_t$ (13)

In this thesis, there are two hypotheses, first is to test whether the nuclear event have an impact on the futures contract on day t and if so, is it statistically significantly positive or negative. The first hypothesis is showed as below:

H0: $AAR_t = 0$

H1: $AAR_t \neq 0$

If the average abnormal return is zero, the nuclear events do not have the effects on the futures contract. If the average abnormal return is different from zero, the nuclear events do have effects on the futures contract. The statistically significant positive average abnormal return means that these nuclear events will bring positive impacts on the futures contracts and the statistically significant negative average abnormal return means that these nuclear events will bring negative impacts on the futures contracts.

The second hypothesis is to test whether the nuclear event has a persistent effect upon the futures contract, and is so, is the effect short-term or medium-term. The second hypothesis is listed as below:

H0: $CAAR_t = 0$

H1: $CAAR_t \neq 0$

If the cumulative average abnormal return is statistically significant in the event window, the nuclear event has a persistent effect upon the futures contract for short-term. And if the cumulative average abnormal return is also statistically significant in the post-event window, the nuclear event has a persistent effect upon the futures contract for medium-term. The persistent cumulative average abnormal return following the event day zero means that when the nuclear disaster happens, the market is not efficient.

3.7 Tests of the Data and Model

3.7.1 Tests of Stationarity of the Series of Daily Returns

I first conduct diagnostic tests of the daily returns for the crude oil and the heating oil futures contracts and for the corresponding S&P 500 stock market index. The results of the Augmented Dickey-Fuller (ADF) test indicate that all return series are stationary.

Table 3.7.1.1 shows the results of the ADF unit root test of the daily returns on the crude oil futures contract and the corresponding daily returns of the S&P 500 index. The t-statistics are significant at the 1% level for both data series, so the null hypothesis of non-stationarity is rejected for both series.

Table 3.7.1.1 Unit Root Tests of the Daily Returns of the Crude Oil Futures Contract and the Corresponding Daily Returns of the S&P 500 Stock Index

Test Critical Values of Crude Oil Futures Contract		t-Statistic of Crude Oil Futures Contract
1% level	-3.431	-69.397***
5% level	-2.862	
10% level	-2.567	
Test Critical Values of S&P 500 Stock Index		t-Statistic of S&P 500 Stock Index
1% level	-3.431	-70.372***
5% level	-2.862	
10% level	-2.567	

, **, * statistically significant at the 10%, 5% and 1% level of significance.*

Table 3.7.1.2 shows the results of the ADF unit root tests of the daily returns on the heating oil futures contract and the corresponding daily returns of S&P 500 stock index. The results indicate that the null hypothesis of non-stationarity is rejected for both series.

Table 3.7.1.2 Unit Root Tests of the Daily Returns of the Heating Oil Futures Contract and the Corresponding Daily Returns of the S&P 500 Stock Index

Test Critical Values of Heating Oil Futures Contract	t-Statistic of Heating Oil Futures Contract

1% level	-3.431	-87.046***
5% level	-2.862	
10% level	-2.567	
Test Critical Values of S&P 500 Stock Index		t-Statistic of S&P 500 Stock Index
1% level	-3.431	-67.476***
5% level	-2.862	
10% level	-2.567	

, **, * statistically significant at the 10%, 5% and 1% level of significance.*

3.7.2 Tests of Misspecification of the Model of Normal Returns on the Futures Contract in the Estimation Period

Table 3.7.2.1 describes the Ramsey Test of the market models for both markets, for the crude oil futures market, the probability of F test is not significant at 5% level which is larger than 0.05, so I cannot reject the null hypothesis. The null hypothesis here is that the model is not mis-specified. For the heating oil futures market, the P value of the F test is larger than 0.1. This means that even under 10% level situation, the null hypothesis cannot be rejected. In conclusion, for both markets, the market models are correct specified.

Table 3.7.2.1 Ramsey RESET Test for Both Futures Contracts

Markets	F-statistic Value	Prob.F
Crude Oil	3.087	0.079*
Heating Oil	2.559	0.110

, **, * statistically significant at the 10%, 5% and 1% level of significance.*

3.7.3 Tests of the Heteroscedasticity and ARCH Effects in the Residuals of Each Series for Futures Contracts

In additional, I also do diagnostic testing on the final OLS models for both contracts, revealing heteroscedasticity and ARCH effects in the residuals of each series. However, the Correlogram-Q test for both contracts indicates that the GARCH (1, 1) – T model can adequately capture these ARCH effects. **Table 3.7.3.1** describes the results of the Correlogram-Q test of GARCH (1, 1) – T model for both futures contracts. For both contracts, the results show that the Q statistics are not significant at the 10% level for all lags which means that the null hypothesis cannot be rejected, indicating the absence of serial correlation in the residuals for both contracts.

Table 3.7.3.1 Correlogram-Q-Statistics for Both Futures Contracts

Crude Oil			Heating Oil		
Lag	Q-Stat	Prob*	Lag	Q-Stat	Prob*
1	0.829	0.363	1	1.685	0.194
2	2.470	0.291	2	3.299	0.192
3	3.275	0.351	3	3.921	0.270
4	4.153	0.386	4	4.577	0.333
5	4.498	0.480	5	4.659	0.459
6	7.980	0.240	6	4.813	0.568
7	8.000	0.333	7	4.910	0.671
8	8.310	0.404	8	5.321	0.723
9	8.781	0.458	9	5.875	0.752
10	9.007	0.531	10	7.512	0.676

11	9.399	0.585	11	7.717	0.738
12	9.401	0.668	12	9.131	0.692
13	9.500	0.734	13	9.672	0.721
14	9.535	0.795	14	10.272	0.742
15	10.54	0.785	15	10.788	0.767
16	10.985	0.810	16	10.824	0.820
17	11.144	0.849	17	11.061	0.853
18	11.280	0.882	18	11.082	0.891
19	12.433	0.866	19	11.437	0.908
20	17.498	0.620	20	12.554	0.896
21	17.785	0.663	21	12.961	0.910
22	18.530	0.674	22	13.386	0.922
23	18.611	0.724	23	13.437	0.942
24	18.611	0.772	24	13.439	0.958
25	18.615	0.815	25	13.967	0.962
26	18.659	0.851	26	14.021	0.973
27	18.660	0.882	27	15.075	0.968
28	19.370	0.886	28	15.505	0.973
29	19.941	0.895	29	16.824	0.965
30	19.954	0.918	30	16.826	0.975
31	20.072	0.934	31	18.579	0.962
32	20.185	0.948	32	21.586	0.918
33	20.185	0.961	33	21.715	0.934

34	22.376	0.937	34	23.922	0.901
35	22.377	0.951	35	23.935	0.921
36	22.382	0.963	36	24.588	0.925

, **, * statistically significant at the 10%, 5% and 1% level of significance.*

3.8 Results of the Empirical Analysis

3.8.1 Results of the Analysis of the CAAR for Each Day in the Event Window and the Post-Event Window

Fig.3.8.1.1 describes the cumulative average abnormal returns (CAAR) for each day in the event window and post- event window from day 0 to day 30 for the three categories: total events, accident-level and incident-level for the crude oil futures contract. First, from the total perspective, the figure shows that the CAAR has a downward trend irrespective of the category of event analyzed. The accident-level category is associated with negative CAAR during all the days in the event window and the post event window. However, for the incident-level category, before day 16, there are still sometimes small positive impacts, but after day 16, the impacts are all negative. In addition, the effect upon the total events category is very similar to the effect upon the incident-level category. This is because for the total of 30 events for the crude oil futures contract, 25 events are at incident-level and only 5 events are at accident-level. Second, from the figure, as expected, the influence of the total events category lies between the influence of the incident-level and the accident-level categories. For the incident-level and the total events categories, the cumulative effect does not differ much between day 0 and day 16. However, following day 16, the variation in the cumulative effect is significant for both categories. For the accident-level category, over the whole event window and post event window, the cumulative effect varies substantially. A visual inspection of the graph suggests that the accident-level category has a significant impact on the path of the CAAR for the crude oil futures contract. In addition, for the accident category events, the cumulative average abnormal return persists in the event window and post-event window, indicating that the market shows an incomplete reaction to the event, leading to downward price adjustments. However, the incident-level and total event categories seem to not influence the CAAR significantly at least until day 16.

Fig 3.8.1.1 CAAR for the Crude Oil Futures Contract for the Three Categories of Events

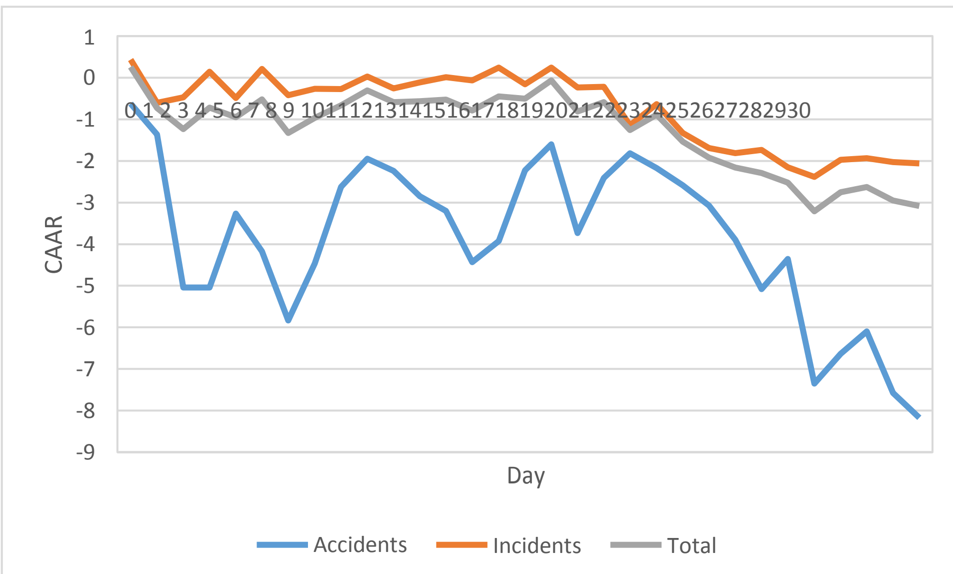
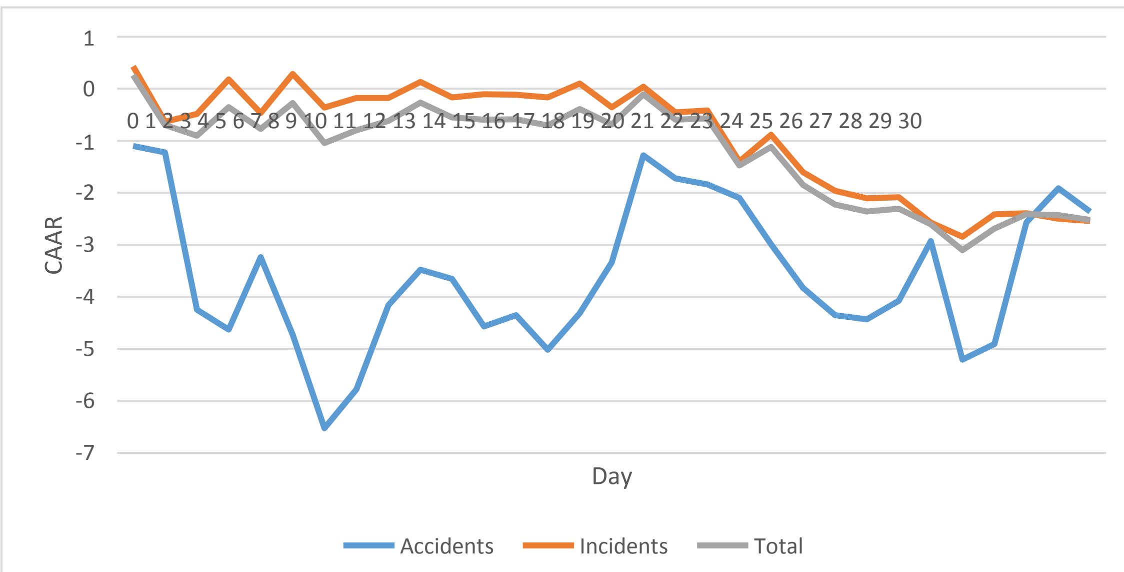


Fig 3.8.1.2 shows the cumulative average abnormal returns (CAAR) for each day in the event window and post- event window from day 0 to day 30 for the three categories: total events, accident-level and incident-level for the heating oil futures contract. As same as what is found in the crude oil futures contract, the accident-level category of events have more impact than the incident-level category and the impact of the total category lies between the two. For each day in the event window and post event window, the CAAR associated with the accident- level category are all significantly negative. From day 0 to day 16, the CAAR associated with the

incident-level and the total events categories are stable and then have a downward trend after day 16. However, comparing to the crude oil futures contract, the difference is that for the heating oil futures contract, the cumulative average abnormal return associated with the accident-level category has an upward trend during the post-event window, indicating that from the perspective of medium-term, the heating oil futures contract adjusts faster to nuclear disasters than the crude oil futures contract.

Figure 3.8.1.2 CAAR for the Heating Oil Futures Contract for the Three Categories of Events



3.8.2 Results of the Analysis of the AAR and CAAR for Each Day in the Event Window and the Post-event Window for Futures Contracts

Table 3.8.2.1 describes the AAR, CAAR and their corresponding t-statistics for three category events of crude oil futures contract. 30, 25 and 5 events are examined for total, incident-level and accident-level category separately. The results show that the total and incident-level category are very similar, this is because among the total 30 events, 25 events are on incident-level. It is obvious that for accident–level events, the average abnormal returns are statistically significant for almost each day in the event window and post-event window except day 3 and day 10. The results illustrate that the accident-level nuclear events will affect the crude oil futures contract for at least 30 days following the event day. In addition, the cumulative average abnormal returns of accident-level events are all statistically significant negative, indicating that for 30 days after the event day, the accident-level nuclear events will bring negative returns to crude oil futures contract. Comparing to accident-level events, the results of total and incident-level events show that the average abnormal returns are statistically significant from day 0 to day 6, indicating that when a nuclear disaster happens, it will affect the crude oil futures contract during the first 6 days following the event day. Then after day 6, the total category events will not affect the crude oil futures contract. For incident-level events, the difference is that from day 15 to day 22, the results are statistically significant except day 18, indicating that the incident-level nuclear events will also have impacts on crude oil futures contract from 15 days to 22 days following the event day. For both the total and incident-level events, the cumulative average abnormal returns are only statistically significant for the first 2 days following the event day and last 10 days in the post-event window which indicates that these two category events will only bring negative returns to crude oil futures contract during the first 2 days following the event day and last 10 days in the post-event window.

Table 3.8.2.1 The AAR, CAAR and Their Corresponding T-statistics for Three Category of Events for the Crude Oil Futures Contract

	Total	Incident	Accident

Day	AAR	CAAR	AAR	CAAR	AAR	CAAR
0	0.261	0.261	0.437**	0.437**	-0.623**	-0.623**
1	-0.989***	-0.728**	-1.038***	-0.600**	-0.744***	-1.367***
2	-0.503**	-1.231***	0.131	-0.469	-3.674***	-5.041***
3	0.511**	-0.72	0.614***	0.145	-0.001	-5.042***
4	-0.23	-0.95*	-0.631***	-0.487	1.778***	-3.264***
5	0.432*	-0.517	0.701***	0.214	-0.910***	-4.174***
6	-0.805***	-1.322**	-0.634***	-0.42	-1.657***	-5.832***
7	0.358	-0.964	0.156	-0.264	1.367***	-4.465***
8	0.302	-0.662	-0.005	-0.269	1.836***	-2.629***
9	0.361	-0.302	0.297*	0.028	0.680***	-1.949**
10	-0.286	-0.588	-0.285*	-0.258	-0.29	-2.239***
11	0.024	-0.564	0.15	-0.108	-0.607**	-2.846***
12	0.043	-0.521	0.124	0.016	-0.361*	-3.207***
13	-0.268	-0.79	-0.076	-0.061	-1.228***	-4.435***
14	0.342	-0.448	0.309*	0.248	0.507**	-3.928***
15	-0.054	-0.502	-0.406**	-0.158	1.705***	-2.223**
16	0.435*	-0.067	0.399**	0.241	0.619**	-1.604*
17	-0.747***	-0.813	-0.470***	-0.229	-2.129***	-3.733***
18	0.228	-0.585	0.009	-0.22	1.320***	-2.413**
19	-0.671	-1.256	-0.924***	-1.144	0.597**	-1.816**
20	0.366	-0.89	0.511***	-0.633	-0.356*	-2.172**
21	-0.646***	-1.536	-0.692***	-1.325*	-0.417**	-2.590**
22	-0.385	-1.92*	-0.365**	-1.690**	-0.482**	-3.072**
23	-0.236	-2.157*	-0.119	-1.809**	-0.821***	-3.893***

24	-0.133	-2.29**	0.078	-1.731**	-1.191***	-5.084***
25	-0.229	-2.519**	-0.421	-2.152**	0.730***	-4.355***
26	-0.69***	-3.209***	-0.229	-2.381***	-2.997***	-7.352***
27	0.46**	-2.75**	0.408**	-1.973**	0.716***	-6.636***
28	0.124	-2.626**	0.041	-1.932**	0.538**	-6.098***
29	-0.326	-2.952**	-0.095	-2.027**	-1.477***	-7.574***
30	-0.127	-3.079**	-0.032	-2.060**	-0.599**	-8.174***

, **, * statistically significant at the 10%, 5% and 1% level of significance*

Table 3.8.2.2 describes the AAR, CAAR and their corresponding t-statistics for three category events of heating oil futures contract. 27, 24 and 3 events are examined for total, incident-level and accident-level category separately. The results of heating oil futures contract is very similar to the results of the crude oil futures contract. For accident–level events, the average abnormal returns are statistically significant for both event window and post-event window except day 1, day 10, day 12, day 18 and day 23. The results illustrate that the accident-level nuclear events will affect the heating oil futures contract for at least 30 days after the day that the nuclear event happens. In addition, the cumulative average abnormal returns of accident-level events are all statistically significant negative, indicating that the accident-level nuclear events will bring negative returns to heating oil futures contract for 30 days after the event day. The difference is that for crude oil futures contract, the cumulative average abnormal returns are still significant at 1% level on day 30, however, for heating oil futures contract, the cumulative average abnormal return is only significant at 10% level on day 29 and at 5% level on day 30. This is consistent with the conclusion I got from **Fig 3.8.1.2** which is that the cumulative average abnormal return associated with the accident-level category has an upward trend. This means that from the perspective of medium-term, the heating oil futures contract adjusts faster to nuclear disasters than the crude oil futures contract.

For total and incident-level events, the results show that the average abnormal returns are still statistically significant from day 0 to day 6. But the difference is that from day 15 to day 22, the results of both the total and incident-level events are statistically significant except day 15 for total category and day 18 for both two categories. For heating oil futures contract, the cumulative average abnormal returns of both total and incident-level events are exactly the same as crude oil futures contract which is that the cumulative average abnormal returns are only statistically significant for the first 2 days following the event day and last 10 days in the post-event window.

Table 3.8.2.2 The AAR, CAAR and Their Corresponding T-statistics for Three Category of Events for the Heating Oil Futures Contract

	Total		**Incident**		**Accident**	
day	AAR	CAAR	AAR	CAAR	AAR	CAAR
0	0.261	0.261	0.431**	0.431**	-1.100***	-1.100***
1	-0.959***	-0.698**	-1.064***	-0.632**	-0.125	-1.225**
2	-0.204	-0.903**	0.148	-0.485	-3.020***	-4.245***
3	0.546**	-0.356	0.663***	0.178	-0.383***	-4.628***
4	-0.420**	-0.776*	-0.646***	-0.469	1.391***	-3.237***
5	0.503**	-0.274	0.752***	0.283	-1.491***	-4.728***
6	-0.774***	-1.048*	-0.647***	-0.363	-1.798***	-6.526***
7	0.25	-0.798	0.188	-0.175	0.746**	-5.780***
8	0.177	-0.621	-0.003	-0.178	1.618***	-4.162***

9	0.352*	-0.269	0.31	0.132	0.685**	-3.477***
10	-0.286	-0.555	-0.3	-0.167	-0.178	-3.655***
11	-0.042	-0.597	0.067	-0.1	-0.914***	-4.569***
12	0.008	-0.588	-0.017	-0.118	0.215	-4.354***
13	-0.116	-0.704	-0.047	-0.165	-0.663**	-5.017***
14	0.313	-0.391	0.264	0.1	0.705**	-4.312***
15	-0.299	-0.689	-0.458**	-0.358	0.974***	-3.338**
16	0.582***	-0.107	0.398*	0.04	2.057***	-1.281*
17	-0.489**	-0.596	-0.495**	-0.455	-0.439**	-1.720**
18	0.023	-0.573	0.04	-0.415	-0.118	-1.838**
19	-0.901***	-1.474	-0.981***	-1.396	-0.261*	-2.099**
20	0.355*	-1.119	0.510**	-0.886	-0.889***	-2.988**
21	-0.733***	-1.852*	-0.719***	-1.605	-0.843**	-3.831**
22	-0.378*	-2.230**	-0.360*	-1.965*	-0.521**	-4.352***
23	-0.132	-2.362**	-0.138	-2.103**	-0.081	-4.433***
24	0.053	-2.309**	0.015	-2.088*	0.359*	-4.074**
25	-0.3	-2.609**	-0.481**	-2.569**	1.145***	-2.929**
26	-0.497**	-3.106***	-0.274	-2.844**	-2.277***	-5.206***
27	0.418**	-2.688**	0.433**	-2.411**	0.300*	-4.906***
28	0.273	-2.415**	0.015	-2.396**	2.343***	-2.563**
29	-0.017	-2.432**	-0.1	-2.496**	0.650**	-1.913*
30	-0.089	-2.520**	-0.043	-2.540**	-0.452**	-2.365**

, **, * statistically significant at the 10%, 5% and 1% level of significance*

4. Conclusion

In this thesis, I use the event study methodology to examine the effect of nuclear events on the crude oil and the heating oil futures contracts. I examine a total of 30 events for the crude oil futures contract and 27 events for the heating oil futures contract. The events are classified into three categories, which are: 1) the incident-level category of events (level 1 to level 3), 2) the accident-level category of events (level 4 to level 7), and; 3) the total category, which includes both incident level and accident level categories. My objective is to address the relationship between the severity of the event and the impact on the futures contracts. I examine two questions: 1) Does the nuclear event have an impact on the futures contract on day t and if so, is it statistically significantly positive or negative? 2) Does the nuclear event have a persistent effect upon the futures contract, and is so, is the effect short-term or medium-term in nature? The results show that the impact of accident-level events upon both futures contracts is statistically significantly negative. However, for incident-level and the total category of events, the cumulative average abnormal returns are only statistically significant negative for the first 2 days following the event day and the last 10 days in the post-event window. The results also show that the accident-level category has a persistent impact upon the futures contracts beyond the event date, however, this is not the case for the incident-level and the total events categories. In addition, it appears, that when all events are taken into consideration, that the heating oil futures contract adjusts faster to the information about the nuclear disaster, since the impact does not persist for as long as for the crude oil futures contract. In conclusion, the impacts of the nuclear events are related to their severity. The lower level events do not impact both futures contracts, while the higher level events do. In theory, when a nuclear disaster occurs, the supply of nuclear energy will decline and the demand for energy provided by crude oil and heating oil should increase which should lead to positive returns to both futures contracts. However, the results of my empirical tests indicate that t nuclear events are associated with negative returns for both futures contracts. This could be because, when a nuclear disaster occurs, the demand for energy inputs to the nuclear reactor could diminish. These inputs could include crude oil and In my thesis, because of the overlapping of multiple nuclear events, I only examine the short-term effect of the nuclear event, over the event window, and the medium-term impact, over the period of the post-event window.. The empirical analysis conducted could be extended to address the long-term impact, given enough non-overlapping nuclear events.

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Appendix

Table 1 List of the Nuclear Events Examined for the Crude Oil Futures Contract

Event	Date	INES	Location
1	1983-09-23	4	Buenos Aires, Argentina
2	1984-07-17	3	Sellafield, UK
3	1986-04-26	7	Kiev, Ukraine
4	1987-12-17	1	Hesse, Germany
5	1988-05-12	2	France
6	1989-12-19	3	VandellÃ²s, Spain
7	1992-06-28	2	Sweden
8	1993-04-06	4	Tomsk, Russia
9	1997-11-03	3	Ibaraki Prefecture, Japan
10	1999-06-18	2	Shika, Ishikawa, Japan
11	1999-09-30	4	Ibaraki Prefecture, Japan
12	2001-08-12	2	Germany
13	2001-12-14	1	Germany
14	2002-11-22	2	Trhange, Belgium
15	2003-04-10	3	Paks, Hungary
16	2003-11-19	2	La Hague, France
17	2004-05-16	1	Lorraine, France
18	2005-04-19	3	Seascale, United Kingdom

19	2006-03-06	2	Erwin, Tennessee, United States
20	2008-07-13	1	Tricastin, France
21	2009-06-10	2	Cadarache, France
22	2009-12-01	2	Cruas-Meysse 4, France
23	2011-03-11	7	Fukushima Prefecture, Japan
24	2011-12-21	2	Cattenom, France
25	2012-04-05	1	Dieppe, France
26	2012-09-01	2	Busan, South Korea
27	2013-04-24	2	Blayais, France
28	2013-09-26	2	Petten, Netherlands
29	2014-05-17	1	Tarapur, Maharashtra, India
30	2015-08-18	2	Blayais, France

Table 2 List of the Nuclear Events Examined for the Heating Oil Futures Contract

Event	Date	INES	Location
1	1987-12-17	1	Hesse, Germany
2	1988-05-12	2	France
3	1989-12-19	3	VandellÃ²s, Spain
4	1992-06-28	2	Sweden
5	1993-04-06	4	Tomsk, Russia
6	1997-11-03	3	Ibaraki Prefecture, Japan

7	1999-06-18	2	Shika, Ishikawa, Japan
8	1999-09-30	4	Ibaraki Prefecture, Japan
9	2001-08-12	2	Germany
10	2001-12-14	1	Germany
11	2002-11-22	2	Trhange, Belgium
12	2003-04-10	3	Paks, Hungary
13	2003-11-19	2	La Hague, France
14	2004-05-16	1	Lorraine, France
15	2005-04-19	3	Seascale, United Kingdom
16	2006-03-06	2	Erwin, Tennessee, United States
17	2008-07-13	1	Tricastin, France
18	2009-06-10	2	Cadarache, France
19	2009-12-01	2	Cruas-Meysse 4, France
20	2011-03-11	7	Fukushima Prefecture, Japan
21	2011-12-21	2	Cattenom, France
22	2012-04-05	1	Dieppe, France
23	2012-09-01	2	Busan, South Korea
24	2013-04-24	2	Blayais, France
25	2013-09-26	2	Petten, Netherlands
26	2014-05-17	1	Tarapur, Maharashtra, India
27	2015-08-18	2	Blayais, France

Table 3 Results of GARCH (1, 1) Model with a Student's T Distribution for Three Categories of Crude Oil Futures Contract

Total		Incident		Accident	
Event1		Event1		Event1	
Variable	Coefficient	Variable	Coefficient	Variable	Coefficient
S&P 500	0.006	S&P 500	0.002	S&P 500	0.006
Intercept	0.049***	Intercept	-0.183	Intercept	0.049***
w	0.049	w	0.048	w	0.049
μ	0.005	μ	0.001	μ	0.005
r	0.012***	r	0.007	r	0.012***
Event2		Event2		Event2	
Variable	Coefficient	Variable	Coefficient	Variable	Coefficient
S&P 500	0.002	S&P 500	0.007	S&P 500	-3.471***
Intercept	-0.183	Intercept	-0.408***	Intercept	2.304***
w	0.048	w	0.094	w	13.079*
μ	0.001	μ	0.007	μ	0.003*
r	0.007	r	0.015***	r	0.009***
Event3		Event3		Event3	
Variable	Coefficient	Variable	Coefficient	Variable	Coefficient
S&P 500	-3.471***	S&P 500	-0.123	S&P 500	-0.501**
Intercept	2.304***	Intercept	0.183	Intercept	-0.098
w	13.079*	w	1.757	w	0.581**
μ	0.003*	μ	0.003	μ	0.011

r	0.009***	r	0.009**	r	0.001**
Event4		Event4		Event4	
Variable	Coefficient	Variable	Coefficient	Variable	Coefficient
S&P 500	0.007	S&P 500	0.124	S&P 500	-0.22
Intercept	-0.408***	Intercept	0.296**	Intercept	0.520*
w	0.094	w	0.123	w	0.149
μ	0.007	μ	0.013**	μ	0.004
r	0.015***	r	0.002	r	0.013*
Event5		Event5		Event5	
Variable	Coefficient	Variable	Coefficient	Variable	Coefficient
S&P 500	-0.123	S&P 500	-0.06	S&P 500	-0.99
Intercept	0.183	Intercept	0.057	Intercept	-0.166
w	1.757	w	0.039	w	4.842***
μ	0.003	μ	0.003	μ	0.004
r	0.009**	r	0.013***	r	0.005
Event6		Event6			
Variable	Coefficient	Variable	Coefficient		
S&P 500	0.124	S&P 500	-0.116		
Intercept	0.296**	Intercept	0.067		
w	0.123	w	0.033		
μ	0.013**	μ	0.004		
r	0.002	r	0.014***		
Event7		Event7			
Variable	Coefficient	Variable	Coefficient		

S&P 500	-0.06	S&P 500	0.348
Intercept	0.057	Intercept	0.371***
w	0.039	w	0.284
μ	0.003	μ	0.004
r	0.013***	r	0.013**
Event8		Event8	
Variable	Coefficient	Variable	Coefficient
S&P 500	-0.501**	S&P 500	-0.4
Intercept	-0.098	Intercept	0.289
w	0.581**	w	1.823
μ	0.011	μ	0.001**
r	0.001**	r	0.006
Event9		Event9	
Variable	Coefficient	Variable	Coefficient
S&P 500	-0.116	S&P 500	-0.441
Intercept	0.067	Intercept	-0.739
w	0.033	w	1.384
μ	0.004	μ	0.003
r	0.014***	r	0.006**
Event10		Event10	
Variable	Coefficient	Variable	Coefficient
S&P 500	0.348	S&P 500	-0.034
Intercept	0.371***	Intercept	-0.344
w	0.284	w	-0.056

μ	0.004	μ	0.003
r	0.013**	r	0.014**
Event11		Event11	
Variable	Coefficient	Variable	Coefficient
S&P 500	-0.22	S&P 500	-1.765***
Intercept	0.520*	Intercept	-0.301
w	0.149	w	4.432**
μ	0.004	μ	0.006
r	0.013*	r	0.002***
Event12		Event12	
Variable	Coefficient	Variable	Coefficient
S&P 500	-0.4	S&P 500	-0.2
Intercept	0.289	Intercept	-0.013
w	1.823	w	1.893
μ	0.001**	μ	0.002**
r	0.006	r	0.006
Event13		Event13	
Variable	Coefficient	Variable	Coefficient
S&P 500	-0.441	S&P 500	0.983***
Intercept	-0.739	Intercept	0.952***
w	1.384	w	0.037
μ	0.003	μ	0.003*
r	0.006**	r	0.013***
Event14		Event14	

Variable	Coefficient	Variable	Coefficient
S&P 500	-0.034	S&P 500	-0.495
Intercept	-0.344	Intercept	0.236
w	-0.056	w	-0.041
μ	0.003	μ	0.003
r	0.014**	r	0.013
Event15		Event15	
Variable	Coefficient	Variable	Coefficient
S&P 500	-1.765***	S&P 500	-0.463
Intercept	-0.301	Intercept	0.182
w	4.432**	w	2.159***
μ	0.006	μ	0.003
r	0.002***	r	0.007
Event16		Event16	
Variable	Coefficient	Variable	Coefficient
S&P 500	-0.2	S&P 500	-1.17
Intercept	-0.013	Intercept	-0.165
w	1.893	w	1.544***
μ	0.002**	μ	0.006
r	0.006	r	0.003
Event17		Event17	
Variable	Coefficient	Variable	Coefficient
S&P 500	0.983***	S&P 500	0.876
Intercept	0.952***	Intercept	0.7

w	0.037	w	1.509
μ	0.003*	μ	0.002
r	0.013***	r	0.006
Event18		Event18	
Variable	Coefficient	Variable	Coefficient
S&P 500	-0.495	S&P 500	1.039
Intercept	0.236	Intercept	0.259
w	-0.041	w	1.314**
μ	0.003	μ	0.002
r	0.013	r	0.007
Event19		Event19	
Variable	Coefficient	Variable	Coefficient
S&P 500	-0.463	S&P 500	0.525
Intercept	0.182	Intercept	0.185
w	2.159***	w	1.155
μ	0.003	μ	0.008
r	0.007	r	0.001
Event20		Event20	
Variable	Coefficient	Variable	Coefficient
S&P 500	-1.17	S&P 500	0.501
Intercept	-0.165	Intercept	0.052
w	1.544***	w	1.384*
μ	0.006	μ	0.004
r	0.003	r	0.005

Event21		Event21	
Variable	Coefficient	Variable	Coefficient
S&P 500	0.876	S&P 500	1.476***
Intercept	0.7	Intercept	0.258**
w	1.509	w	0.041
μ	0.002	μ	0.003
r	0.006	r	0.013***

Event22		Event22	
Variable	Coefficient	Variable	Coefficient
S&P 500	1.039	S&P 500	0.788***
Intercept	0.259	Intercept	-0.372***
w	1.314**	w	0.402
μ	0.002	μ	0.003**
r	0.007	r	0.008***

Event23		Event23	
Variable	Coefficient	Variable	Coefficient
S&P 500	-0.99	S&P 500	-0.154
Intercept	-0.166	Intercept	-0.142
w	4.842***	w	0.283
μ	0.004	μ	0.005**
r	0.005	r	0.013***

Event24		Event24	
Variable	Coefficient	Variable	Coefficient
S&P 500	0.525	S&P 500	0.157

Intercept	0.185	Intercept	0.054
w	1.155	w	0.076
μ	0.008	μ	0.004
r	0.001	r	0.013***

Event25		Event25	
Variable	Coefficient	Variable	Coefficient
S&P 500	0.501	S&P 500	0.872**
Intercept	0.052	Intercept	-0.902***
w	1.384*	w	1.541
μ	0.004	μ	0.001***
r	0.005	r	0.006

Event26	
Variable	Coefficient
S&P 500	1.476***
Intercept	0.258**
w	0.041
μ	0.003
r	0.013***

Event27	
Variable	Coefficient
S&P 500	0.788***
Intercept	-0.372***
w	0.402
μ	0.003**

r	0.008***

Event28	
Variable	Coefficient
S&P 500	-0.154
Intercept	-0.142
w	0.283
μ	0.005**
r	0.013***

Event29	
Variable	Coefficient
S&P 500	0.157
Intercept	0.054
w	0.076
μ	0.004
r	0.013***

Event30	
Variable	Coefficient
S&P 500	0.872**
Intercept	-0.902***
w	1.541
μ	0.001***
r	0.006

, **, * statistically significant at the 10%, 5% and 1% level of significance*

Table 4 Results of GARCH (1, 1) Model with a Student's T Distribution for Three Categories of Heating Oil Futures Contract

Total		Incident		Accident	
Event1		Event1		Event5	
Variable	Coefficient	Variable	Coefficient	Variable	Coefficient
S&P 500	0.007	S&P 500	0.007	S&P 500	-0.501**
Intercept	-0.408***	Intercept	-0.408***	Intercept	-0.098
w	0.094	w	0.094	w	0.581**
μ	0.007	μ	0.007	μ	0.011
r	0.015***	r	0.015***	r	0.001**
Event2		Event2		Event8	
Variable	Coefficient	Variable	Coefficient	Variable	Coefficient
S&P 500	-0.123	S&P 500	-0.123	S&P 500	-0.22
Intercept	0.183	Intercept	0.183	Intercept	0.520*
w	1.757	w	1.757	w	0.149
μ	0.003	μ	0.003	μ	0.004
r	0.009**	r	0.009**	r	0.013*
Event3		Event3		Event20	
Variable	Coefficient	Variable	Coefficient	Variable	Coefficient
S&P 500	0.124	S&P 500	0.124	S&P 500	-0.99
Intercept	0.296**	Intercept	0.296**	Intercept	-0.166
w	0.123	w	0.123	w	4.842***
μ	0.013**	μ	0.013**	μ	0.004
r	0.002	r	0.002	r	0.005

Event4		Event4	
Variable	Coefficient	Variable	Coefficient
S&P 500	-0.06	S&P 500	-0.06
Intercept	0.057	Intercept	0.057
w	0.039	w	0.039
μ	0.003	μ	0.003
r	0.013***	r	0.013***

Event5		Event5	
Variable	Coefficient	Variable	Coefficient
S&P 500	-0.501**	S&P 500	-0.116
Intercept	-0.098	Intercept	0.067
w	0.581**	w	0.033
μ	0.011	μ	0.004
r	0.001**	r	0.014***

Event6		Event6	
Variable	Coefficient	Variable	Coefficient
S&P 500	-0.116	S&P 500	0.348
Intercept	0.067	Intercept	0.371***
w	0.033	w	0.284
μ	0.004	μ	0.004
r	0.014***	r	0.013**

Event7		Event7	
Variable	Coefficient	Variable	Coefficient
S&P 500	0.348	S&P 500	-0.4

Intercept	0.371***	Intercept	0.289
w	0.284	w	1.823
μ	0.004	μ	0.001**
r	0.013**	r	0.006

Event8		Event8	
Variable	Coefficient	Variable	Coefficient
S&P 500	-0.22	S&P 500	-0.441
Intercept	0.520*	Intercept	-0.739
w	0.149	w	1.384
μ	0.004	μ	0.003
r	0.013*	r	0.006**

Event9		Event9	
Variable	Coefficient	Variable	Coefficient
S&P 500	-0.4	S&P 500	-0.034
Intercept	0.289	Intercept	-0.344
w	1.823	w	-0.056
μ	0.001**	μ	0.003
r	0.006	r	0.014**

Event10		Event10	
Variable	Coefficient	Variable	Coefficient
S&P 500	-0.441	S&P 500	-1.765***
Intercept	-0.739	Intercept	-0.301
w	1.384	w	4.432**
μ	0.003	μ	0.006

r	0.006**	r	0.002***
Event11		Event11	
Variable	Coefficient	Variable	Coefficient
S&P 500	-0.034	S&P 500	-0.2
Intercept	-0.344	Intercept	-0.013
w	-0.056	w	1.893
μ	0.003	μ	0.002**
r	0.014**	r	0.006
Event12		Event12	
Variable	Coefficient	Variable	Coefficient
S&P 500	-1.765***	S&P 500	0.983***
Intercept	-0.301	Intercept	0.952***
w	4.432**	w	0.037
μ	0.006	μ	0.003*
r	0.002***	r	0.013***
Event13		Event13	
Variable	Coefficient	Variable	Coefficient
S&P 500	-0.2	S&P 500	-0.495
Intercept	-0.013	Intercept	0.236
w	1.893	w	-0.041
μ	0.002**	μ	0.003
r	0.006	r	0.013
Event14		Event14	
Variable	Coefficient	Variable	Coefficient

S&P 500	0.983***	S&P 500	-0.463
Intercept	0.952***	Intercept	0.182
w	0.037	w	2.159***
μ	0.003*	μ	0.003
r	0.013***	r	0.007

Event15		Event15	
Variable	Coefficient	Variable	Coefficient
S&P 500	-0.495	S&P 500	-1.17
Intercept	0.236	Intercept	-0.165
w	-0.041	w	1.544***
μ	0.003	μ	0.006
r	0.013	r	0.003

Event16		Event16	
Variable	Coefficient	Variable	Coefficient
S&P 500	-0.463	S&P 500	0.876
Intercept	0.182	Intercept	0.7
w	2.159***	w	1.509
μ	0.003	μ	0.002
r	0.007	r	0.006

Event17		Event17	
Variable	Coefficient	Variable	Coefficient
S&P 500	-1.17	S&P 500	1.039
Intercept	-0.165	Intercept	0.259
w	1.544***	w	1.314**

μ	0.006	μ	0.002
r	0.003	r	0.007
Event18		Event18	
Variable	Coefficient	Variable	Coefficient
S&P 500	0.876	S&P 500	0.525
Intercept	0.7	Intercept	0.185
w	1.509	w	1.155
μ	0.002	μ	0.008
r	0.006	r	0.001
Event19		Event19	
Variable	Coefficient	Variable	Coefficient
S&P 500	1.039	S&P 500	0.501
Intercept	0.259	Intercept	0.052
w	1.314**	w	1.384*
μ	0.002	μ	0.004
r	0.007	r	0.005
Event20		Event20	
Variable	Coefficient	Variable	Coefficient
S&P 500	-0.99	S&P 500	1.476***
Intercept	-0.166	Intercept	0.258**
w	4.842***	w	0.041
μ	0.004	μ	0.003
r	0.005	r	0.013***
Event21		Event21	

Variable	Coefficient	Variable	Coefficient
S&P 500	0.525	S&P 500	0.788***
Intercept	0.185	Intercept	-0.372***
w	1.155	w	0.402
μ	0.008	μ	0.003**
r	0.001	r	0.008***

Event22		Event22	
Variable	Coefficient	Variable	Coefficient
S&P 500	0.501	S&P 500	-0.154
Intercept	0.052	Intercept	-0.142
w	1.384*	w	0.283
μ	0.004	μ	0.005**
r	0.005	r	0.013***

Event23		Event23	
Variable	Coefficient	Variable	Coefficient
S&P 500	1.476***	S&P 500	0.157
Intercept	0.258**	Intercept	0.054
w	0.041	w	0.076
μ	0.003	μ	0.004
r	0.013***	r	0.013***

Event24		Event24	
Variable	Coefficient	Variable	Coefficient
S&P 500	0.788***	S&P 500	0.872**
Intercept	-0.372***	Intercept	-0.902***
w	0.402	w	1.541
μ	0.003**	μ	0.001***

r	0.008***	r	0.006

Event25	
Variable	Coefficient
S&P 500	-0.154
Intercept	-0.142
w	0.283
μ	0.005**
r	0.013***

Event26	
Variable	Coefficient
S&P 500	0.157
Intercept	0.054
w	0.076
μ	0.004
r	0.013***

Event27	
Variable	Coefficient
S&P 500	0.872**
Intercept	-0.902***
w	1.541
μ	0.001***
r	0.006

, **, * statistically significant at the 10%, 5% and 1% level of significance*

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