The Effect of the Fukushima Nuclear Accident on Stock Prices of Electric Power Utilities[+]

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ABSTRACT

The purpose of this study is to investigate the effect of the accident at the Fukushima Daiichi nuclear power station, which is owned by Tokyo Electric Power Co. (TEPCO), on the stock prices of the other electric power utilities in Japan. Because the other utilities were not directly damaged by the Fukushima nuclear accident, their stock price responses should reflect the change in investor perceptions on risk and return associated with nuclear power generation. Our first finding is that the stock prices of utilities that own nuclear power plants declined more sharply after the accident than did the stock prices of other electric power utilities. In contrast, investors did not seem to care about the risk that may arise from the use of the same type of nuclear power reactors as those at the Fukushima Daiichi station. We also observe an increase of both systematic and total risks in the post-Fukushima period, indicating that negative market reactions are not merely caused by one-time losses but by structural changes in society and regulation that could increase the costs of operating a nuclear power plant.

Keywords: nuclear accident; electric power utility; capital markets
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1. Introduction

On March 11, 2011, following the East Japan great earthquake and tsunami, failure occurred in three of the six nuclear reactors at the Fukushima Daiichi nuclear power station owned by Tokyo Electric Power Co. (TEPCO). Based on the evidence of partial nuclear meltdowns in these nuclear reactors, on April 12, the Nuclear and Industrial Safety Agency (NISA) raised the crisis level of the Fukushima nuclear accident to 7 based on the International Nuclear Event Scale (INES), a level that had previously only been applied to the Chernobyl accident in the former Soviet Union in 1986. Following the event at the Fukushima Daiichi station, the planned construction of several nuclear power plants was stopped; safety rules were tightened; the operation of several existing nuclear power plants was suspended due to regular or emergent inspections; and the resumption of operation of the inspected nuclear plants was postponed. The social movements to halt nuclear power plants have gained strength and continue.

From the viewpoint of investors, stocks of electric power utilities have long been regarded as defensive stocks that are not affected by economic conditions and thus provide stable dividends. However, recent changes in the attitudes of the public and of the industry regulators suggest increased uncertainty surrounding future cash flows of these utilities. The purpose of this study is to investigate the effect of the accident at the Fukushima Daiichi nuclear power station on the stock prices of electric power utilities in Japan. Specifically, we estimate the cumulative abnormal returns (*CAR*s) by using the market model based on the pre-Fukushima period estimation windows.

Prior studies examining stock price reactions to nuclear accidents focus on the previous two big nuclear accidents, at Three Mile Island (TMI) in 1979 and Chernobyl in 1986. These studies report that in each case, stock prices of utility securities declined sharply after the accident, particularly for firms with a major commitment to nuclear power generation (Bowen et al. 1983; Hill and Schneeweis 1983; Fields and Janjigian 1989; Kalra et al. 1993). The first explanation for this decline is a downward adjustment in future cash flows from nuclear power generation, which was caused by the anticipation of plant inspections, suspension, and higher costs arising from stricter regulation. The second explanation is an increase of long-term systematic risk caused by structural changes in market perceptions, although prior studies provide mixed results regarding the increase of systematic risk.

The Fukushima accident has both similarities to and differences from the prior two accidents. First, the Fukushima Daiichi nuclear power station is owned by a public company, TEPCO. While TMI is also owned by a public company, General Public Utility (GPU), Chernobyl is owned by the national government. At the same time, the

Fukushima and Chernobyl accidents are far more serious accidents than TMI, as both of them are labeled as crisis level 7 based on the INES.

The Fukushima nuclear accident is thus the first serious nuclear accident to occur in a public company in the Western world. The negative impact of the Fukushima accident is likely to decrease future cash flow of all electric power utilities that own nuclear power plants in Japan by increasing the costs of power generation and the cost-sharing of the compensation payments following the Fukushima Daiichi accident. We conjecture that the Fukushima accident may have generated more negative market responses than prior nuclear accidents as well as increased systematic risk.

In this paper, our focus is on stock price reactions of electric power utilities other than TEPCO and Tohoku Electric Power Co. Because the other companies were not directly damaged by natural disasters and the resulting Fukushima nuclear accident, their stock price responses should reflect the change in investor perceptions of risk and return associated with nuclear power plants. We report the following five main findings. First, the stock prices of the firm hit by the earthquake declined more sharply than did those of the other electric power utilities. Second, the stock prices of utilities that own nuclear power plants declined more sharply than did those of electric power utilities without nuclear power plants.

Third, shareholders did not seem to care about whether electric power utilities own nuclear power reactors similar to those at the Fukushima Daiichi station. In particular, market reactions were not different between utilities with old nuclear power reactors built in the 1970s and those without them, or between utilities with the Mark 1 nuclear reactor container and those without it. Lastly, we observe an increase of both systematic and total risks in the post-accident period, indicating that negative market reactions are not merely caused by one-time losses but by structural changes in society and regulation that could increase the costs of operating a nuclear power plant.

The rest of this article is organized as follows. Section 2 provides background information, literature review, and hypotheses development. Section 3 describes our methodology and data. Section 4 discusses empirical results. Sensitivity analysis and concluding remarks are provided in Sections 5 and 6, respectively.

2. Background information, literature review, and hypotheses development

2.1. Background

Japan's electric power utilities are regulated by the Electricity Business Act of 1964. Article 2 (1) of the Act classifies the electricity business into four categories: general electricity business, wholesale electricity business, specified electricity business, and specified-scale electricity utility. General electricity business is conducted by ten local monopolies, each of which supplies electricity to meet the general demand in a local area. These companies are named after the local area where they are operating, i.e., Tokyo, Tohoku, Chubu, Kansai, Chugoku, Hokuriku, Shikoku, Kyushu, Hokkaido, and Okinawa. All of them are public companies. These companies provide users with more than 99% of the electricity used in Japan (Yamaguchi 2007).

Wholesale electricity business is conducted by two utilities, namely, J-Power and the Japan Atomic Power Company (JAPC). While J-Power is a public company, JAPC is not. These companies supply local monopolies with electricity to be used for their general electricity business. Specified electricity business is conducted by five utilities, each of which supplies electricity to meet the demand in a specified area. Specified-scale electricity business is conducted by 35 utilities, each of which supplies electricity to meet a large-scale demand from electricity users. Both specified electricity utilities and specified-scale electricity utilities are minor providers of electricity and thus are excluded from our research focus.

As will be further explained in Section 3, our sample consists of ten local monopolies that supply general electricity business and J-Power, one of the wholesale electricity utilities. All of these companies are listed on the first section of the Tokyo Stock Exchange and supply more than 99% of the electricity used in Japan. Among eleven sample firms, only Okinawa Electric Power Co. (OEPC) and J-Power do not operate nuclear power plants, though J-Power has a nuclear power plant under construction. According to the Agency for Natural Resources and Energy, nuclear power generation supplied 32% of the electricity generated in Japan in fiscal year 2010.

On March 11, 2011, following the East Japan great earthquake and tsunami, failure occurred in three of the six nuclear reactors at the Fukushima Daiichi nuclear power station owned by TEPCO. The earthquake cut the external power supply to the nuclear power plants, while the tsunami neutralized diesel generators that were meant to be available for emergencies. The loss of power crippled the reactor's coolant, resulting in explosions, radiant leaks, and meltdowns. On the basis of these developments, on April 12, the NISA raised the crisis level of the Fukushima nuclear accident to 7, a level that had only been applied previously to the Chernobyl accident in the former Soviet Union in 1986.

Several researchers have suggested that the Mark 1 reactor container, which is used in five nuclear reactors at the Fukushima Daiichi nuclear power station, may have precipitated an accident. The Mark 1 reactor container was developed for use with boiling water reactors (BWR) by General Electric (GE) in the 1960s. In 1975, several researchers at GE identified a potential problem of the Mark 1 reactor container, which was that it might not handle the dynamic loads that could be experienced with a loss of the cooling system (Mosk 2011). Because a loss of power and coolant occurred in the Fukushima nuclear accident, the use of the Mark 1 reactor container may have had an effect on the explosion and the radiant leaks. Currently, Mark 1 reactor containers are employed by one reactor owned by Tohoku Electric Power Co. and one reactor owned by Chugoku Electric Power Co. as well as the five reactors at the Fukushima Daiichi station.[1]

Other researchers have expressed concerns about the aging of nuclear power reactors (Saito 2011). The Fukushima Daiichi nuclear power reactors were built in the 1970s. Although the Japanese laws do not specify how long nuclear power plants can be in operation, the NISA specifies that nuclear power plants that have been operating more than 30 years are subject to the aging management, which means they should undergo inspections to be allowed to extend their operations for another 10 years. In the 2000s, the Japanese government changed its stance on the aging reactors and decided to approve 10-year extensions up to two times.

After the Fukushima Daiichi accident, the NISA started to revise the procedure for assessing aging nuclear power plants on November 29, 2011. In addition, the government minister announced to set 40-year limits on nuclear reactor operation on January 6, 2012. These stricter assessment and regulation, together with the ongoing social movement to halt nuclear power plants,[2] is likely to decrease the future cash flow of electric power utilities by reducing the number of operating nuclear power plants and by increasing the power generation costs.[3]

In fact, reflecting the change in the social atmosphere, the construction of several nuclear power plants has been delayed. In addition, the operation of several existing

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[1] The JAPC also employs the Mark 1 reactor container at one reactor under inspection.

[2] According to an online survey conducted by National Institution of Science and Technology, the share of people who are in favor of pursuing nuclear power generation declined from 50.5% in April 2011 to 35.9% in September 2011. The survey results are available in Japanese at: http://www.nistep.go.jp/nistep/about/pdf/9gatu-made_use-atomic-power.pdf.

[3] The possible increase of power generation costs is likely to result from the increase in the use of costly alternative power generation to cover the possible loss from the reduced use of nuclear power generation, as well as the increase in the costs to meet the stricter regulation of nuclear power plants. According to the Agency for Natural Resources and Energy, nuclear power accounted for 38.7% of the total power generation of 10 general electric utilities in October 2010 but for only 11.5% of this power in October 2011. The share of thermal power generation of these 10 general electric utilities increased from 54.3% to 80.7% during the same period. In addition, on December 19, 2011, the subcommittee of the Cabinet Office's Japan Atomic Energy Commission (JAEC) reports that the cost of nuclear power generation comes to 8.9 yen per kilowatt-hour of electricity, which is a 50% increase from cost estimates in 2004, when the risk of a serious accident is factored in.

nuclear power plants was suspended due to regular or emergent inspections, and the resumption of operation of these plants has been postponed under the mounting pressure to halt the use of nuclear power plants.[4] These events are likely to increase costs for the utilities as well as reduce earnings from operating the facilities. In other words, not only TEPCO but also the other electric power utilities may experience a loss in firm value due to the changes in the social environment.

In addition, both TEPCO and the other general electric utilities may have to share the massive compensation payments for the Fukushima Daiichi nuclear accident. Based on the Act to Establish the Nuclear Damage Compensation Facilitation Corporation, which was enacted in August 2011, the government established a new Nuclear Damage Liability Facilitation Fund in September of that year. The Fund's role is to provide TEPCO with special financial support, so that TEPCO can pay massive compensation to affected people and businesses. The financial source of the Fund is contributions from the other nuclear business operators and government bond issuance. Although the exact amounts of contributions have not been revealed, the third-party committee reported in October 2011 that TEPCO may need to pay 4.5 trillion yen for compensation.[5] Thus, the Fukushima Daiichi nuclear accident is likely to negatively affect future cash flow of all electric power utilities that own nuclear power plants in Japan.

2.2. Literature review

Prior studies that examine stock price reactions to nuclear accidents focus on the previous two big nuclear accidents, namely, TMI in 1979 and Chernobyl in 1986. These studies document that in each case the stock prices of utility securities declined sharply after the accident, particularly for firms with a major commitment to nuclear power generation (Bowen et al. 1983; Hill and Schneeweis 1983; Fields and Janjigian 1989; Kalra et al. 1993). However, these studies provide mixed results with regard to an increase of systematic risk.

Bowen et al. (1983) investigate the impact of TMI on stock returns and systematic risk represented by beta in the standard market model. They find that stock prices of utility securities declined sharply after the accident, particularly for firms with a major commitment to nuclear power generation and for firms with nuclear power plants built by Babcock and Wilcox (BW), a builder of TMI. In addition, they report an increase of

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[4] To ensure safety of nuclear power plants, in July 2011, the government decided to conduct a stricter safety evaluation based on a stress test, which is newly introduced following European countries.

[5] The outline of the report by the third-party committee is available in Japanese at: http://www.cas.go.jp/jp/seisaku/keieizaimutyousa/dai10/siryou2.pdf.

systematic risk, indicating a structural change in the economy. Likewise, Hill and Schneeweis (1983) also studying the impact of TMI, report that market reactions were larger for firms with nuclear-based facilities than non-nuclear firms. In addition, contrary to the finding of Bowen et al (1993), Chen (1984) examines the structural stability of the market model after the TMI accident, finding only an insignificant increase of beta.

Fields and Janjigian (1989), examining the effect of Chernobyl on the U.S. electric utility stock prices, report a similar finding to that in the case of TMI, which is that market reactions are more negative for firms using nuclear power than for nonnuclear firms. However, they find no significant changes in systematic risk or total risk after the Chernobyl accident. Kalra et al. (1993) also find that negative market reactions to the Chernobyl accident were small and transitory for both nuclear and non-nuclear facilities. These prior studies show that both accidents decreased the stock prices of electric power utilities in the U.S. market, though the magnitude of the decline was larger for the TMI accident than for the Chernobyl accident. However, these studies provide mixed results with regard to an increase of systematic risk.

As noted above, the Fukushima accident has both similarities to and differences from the prior two accidents. First, the Fukushima Daiichi nuclear power station and TMI are both owned by public companies (TEPCO and GPU, respectively). Chernobyl is owned by the national government. Because of secrecy of the government of the former Soviet Union, the disclosure about the Chernobyl accident was much less timely and little information was provided. In contrast, the huge number of announcements related to the Fukushima and TMI accidents were likely to generate larger market reactions. Table 1 shows that the number of Nikkei-related newspaper articles that contains the words “nuclear power generation” is 2,522 during the period between March 11 and April 25, 2011 and 6,288 during the period between April 26 and September 30, 2011.

[Table 1 here]

At the same time, the Fukushima and Chernobyl accidents are far more serious accidents than TMI, as both of them are labeled as crisis level 7 based on the INES. The difference is that the negative impact of the Fukushima accident is likely to decrease future cash flow of all electric power utilities that own nuclear power plants in Japan by increasing the costs of power generation and because of the cost-sharing of the compensation payments for the Fukushima Daiichi accident. Considering these characteristics, the Fukushima nuclear accident can be said to be the first serious nuclear accident to occur in a public company in the Western world. Thus, we expect that the Fukushima accident may have generated more negative market responses than prior nuclear accidents as well as increased systematic risk.

2.3. Hypotheses development

As discussed in subsection 2.1., not only TEPCO but the other electric power utilities may experience a loss in firm value due to the changes in the social environment after the Fukushima Daiichi nuclear accident. Given the nature of the incident, the Fukushima Daiichi accident could not have been anticipated, indicating that market prices did not impound it before March 11, 2011. Therefore, a study of the days following the accident should provide evidence and magnitude of a loss in firm value. This phenomenon is observed in prior studies on the TMI and Chernobyl accidents (Bowen et al. 1983; Hill and Schneeweis 1983; Fields and Janjigian 1989; Kalra et al. 1993). Thus, the first hypothesis is as follows:

H_1: *The Fukushima accident and subsequent events negatively affected stock prices of electric power utilities.*

We would expect that electric power utilities in the disaster stricken area suffered from larger losses than did the other electric power utilities, because both physical damages and opportunity loss increase the cost of facilities. Thus, the second hypothesis is as follows:

H_2: *The Fukushima accident and subsequent events affected stock prices more negatively for electric power utilities in the disaster-stricken area than for electric power utilities outside that area.*

In addition, we would expect the opportunity loss for electric power utilities that do not own a nuclear power plant to be smaller than the loss for those utilities already committed to having a nuclear power capacity. The same phenomenon is observed in prior studies on the TMI and Chernobyl accidents (Bowen et al. 1983; Hill and Schneeweis 1983; Fields and Janjigian 1989). Thus, the third hypothesis is as follows:

H_3: The Fukushima accident and subsequent events affected stock prices more negatively for electric power utilities with current nuclear capacity than for electric power utilities with no current nuclear capacity.

In particular, firms that depend largely on nuclear power generation should experience larger opportunity loss by the changes in the social environment. Thus, we will also test for a differential impact on firms that were more dependent on nuclear power generation. We regard firms in which more than 20% of their total power generation comes from nuclear power as those with a major commitment to nuclear power generation. Our fourth hypothesis is thus as follows:

H_4: The Fukushima accident and subsequent events affected stock prices more negatively for electric power utilities with a major commitment to nuclear energy than for electric power utilities with a small commitment to nuclear energy.

Further, firms that use similar types of nuclear power reactors to those at the Fukushima Daiichi nuclear power station should experience the effect of any change in the regulatory environment as well as the effect of being investigated to check their safety. In the TMI accident, firms employing a BW plant experienced more negative stock price reactions (Bowen et al. 1983). As discussed in subsection 2.1., several researchers claim that the use of the Mark 1 nuclear reactor container or the use of old nuclear power plants may have amplified the negative impact of the accident. Thus, we will test for a more negative impact on firms with a Mark 1 nuclear reactor container, and firms with old nuclear power plants that were built in the 1970s, leading to our fifth hypothesis, as follows:

H_5: The Fukushima accident and subsequent events affected stock prices more negatively for electric power utilities with nuclear power reactors similar to the Fukushima Daiichi nuclear power station than for electric power utilities without such reactors.

We note that negative market reactions after the Fukushima Daiichi nuclear accident indicate a one-time loss when the parameters of the asset pricing process utilized in determining stock prices are stable. However, when the parameters have shifted during the post-Fukushima period, negative market reactions suggest a loss caused by structural changes in society. To examine this point, we compare the parameters between the pre- and post-Fukushima periods, and then conduct a Chow test. Our sixth and final hypothesis is as follows:

H_6: There was a structural change in the parameter of the regression model between the pre-and post-Fukushima periods.

3. Data and Methodology

3.1. Data

Our sample consists of 11 electric power utilities that are listed on the first section of the Tokyo Stock Exchange. First, note that TEPCO, owner of the Fukushima Daiichi nuclear station, is excluded from the group categories except for the “All” sample. This is because our focus is not the effect of the Fukushima Daiichi nuclear power accident on TEPCO. While TEPCO experienced direct cash flow reductions resulting from the accident, other electric power utilities are hypothesized to be affected by their dependency on nuclear power plants, by the similarities in nuclear reactors, and by cost-sharing of the compensation payments. It is these interdependencies that are of interest here.

[Table 2 here]

We then partition the sample. Table 2 presents a summary of the 11 electric power utilities by subsample. To test the second hypothesis, we divide samples between Victim and Non-Victim. Victim means an electric power utility that was stricken by the Great East earthquake and tsunami together with TEPCO, which consists only of Tohoku Electric Power Co. The other 9 electric power utilities were not hit by the natural disaster and thus are labeled as Non-Victim.

Since the effect of the accident was hypothesized to be larger on those firms with a commitment to nuclear energy, we divide the Non-Victim sample between NPP (nuclear power plant) and Non-NPP to test the third hypothesis. NPP means an electric power utility that own nuclear power plants, which consists of 7 electric power utilities: Chubu, Kansai, Chugoku, Hokuriku, Shikoku, Kyushu, and Hokkaido. Okinawa and J-Power do not own a nuclear power plant and thus are labeled as Non-NPP.

Similarly, to test the fourth hypothesis, we examine whether the effect of the accident was larger on those firms with a major commitment to nuclear energy. We divide the NPP sample between by LN (large nuclear) and Non-LN. LN means an electric power utility with a major commitment to the production of nuclear energy. We classify utilities with more than 20% of their total power generation comes from nuclear power as LN. Based on the monthly statistics from March 2010 to February 2011, which are provided by the Agency for Natural Resources and Energy, 5 electric companies, namely, Kansai, Hokuriku, Shikoku, Kyushu, and Hokkaido, are partitioned into the LN group.

The fifth hypothesis states that the reaction to the Fukushima accident more severely affected electric power utilities that own nuclear power reactors similar to those at the Fukushima Daiichi nuclear power station. Thus, we divide the Non-NPP sample between those companies with nuclear power reactors similar to those at the Fukushima Daiichi station and the other companies. We focus on two characteristics similar to those of the Fukushima Daiichi station, namely, the use of old nuclear power plants (Old), which were built in the 1970s, and the use of the Mark 1 nuclear power reactor. Note that the Mark 1 sample consists only of Chugoku Electric Power Co. because we exclude Tohoku Electric Power Co from the Non-NPP sample. Other characteristics we use for the comparison include the use of non-old nuclear power plants, which were built after 1980 (Non-Old), and the use of a nuclear reactor container other than a Mark 1 (Non-Mark 1).

3.2. Methodology

In the present study, we analyze the effect of the Fukushima nuclear accident and subsequent events on the stock prices of electric power utilities by using event study methodology. We denote the event day as t_0, the initial date of the event window as t_1, and the final date of the event window as t_2. The length of the event window is expressed as $L_1 = t_2 - t_1 + 1$. To estimate both short-term and long-term effects, we select three event windows $(t_1, t_2) = (0, 2)$, $(0, 30)$, and $(0, 137)$. Denoting the initial date of the estimation window as t_3 and the final date of the estimation window as t_4, we set the estimation window $(t_3, t_4) = (-250, -1)$ with 250 transaction days from March 4, 2010, to March 10, 2011, prior to the Tohoku earthquake.[6] The length of the estimation window is expressed as $L_2=t_4-t_3+1(=250)$. The following market model is then estimated for each portfolio in the estimation window.

$$R_{p,t} = \alpha_p + \beta_p R_{m,t} + \varepsilon_{p,t} \tag{1}$$

The dependent variable $R_{p,t}$ is the return of an equally-weighted portfolio of electric power utilities p on day t. $R_{m,t}$ represents the return of the Tokyo Stock Price

[6] To ensure robustness, we try another estimation window set at 533 trading days from July 6, 2009, to March 10, 2011. The results are presented in Section 5.

Index (TOPIX) on day *t*. $\varepsilon_{p,t}$ represents the zero-mean disturbance term. Using the estimated parameters $\hat{\alpha}_p$ and $\hat{\beta}_p$, we calculate an abnormal return for the stock of portfolio *p* in period *t* as follows:

$$AR_{p,t} = R_{p,t} - (\hat{\alpha}_p + \hat{\beta}_p R_{m,t}) \tag{2}$$

The *CAR* is then obtained by summing the abnormal returns over the event window, as follows:

$$CAR_p(t_1, t_2) = \sum_{t=t_1}^{t_2} AR_{p,t} \tag{3}$$

If the event did not affect stock prices, the *CAR* should be zero. In other words, the null hypothesis H_0 stipulating that $CAR=0$ should be rejected statistically if the event influenced stock prices as stated in our first hypothesis H_1. To test this hypothesis, we normalize *CAR* for each portfolio to get the standardized *CAR* (*SCAR*), as follows:

$$SCAR_p(t_1, t_2) = \frac{CAR_p(t_1, t_2)}{\sigma_p(t_1, t_2)} \sim N(0,1) \tag{4}$$

where $\sigma_p\ (t_1, t_2)$ is the standard deviation of the *CAR*, which is calculated asymptotically by the variance of abnormal returns $\sigma^2_{\varepsilon_p}$ as follows:

$$\sigma_p(t_1, t_2) \approx \sqrt{(t_2 - t_1 + 1)\sigma^2_{\varepsilon_p}} \tag{5}$$

We then examine whether the mean *CAR*s over the event window are statistically different between two pairwise groups of electric power utilities, which are explained in the prior subsection. Specifically, we conduct one-tailed *t*-tests to investigate the validity of the second to fifth hypotheses H_2-H_5.

Last, to test the sixth hypothesis H_6, we first examine whether estimated parameters, β_p as well as variances of returns changed between the pre- and post-Fukushima periods. Then we conduct a Chow test to investigate whether there was a structural change in the parameter of the regression model between the pre-Fukushima period (-250, -1) and the post-Fukushima periods (0,137).

4. Empirical results

4.1. Empirical results on stock price responses of electric power utilities

First, we analyze *CAR*s of Japanese electric power utilities. Table 3 shows that the *CAR*s of the portfolio of all electric power utilities are significantly negative at the 1% level for all event windows. This is consistent with H_1. Specifically, the *CAR* (0, 2) of the portfolio of all electric power utilities (All) is -15.3%, *CAR* (0, 30) is -27.8%, and *CAR* (0, 137) is -30.9%. This indicates that the initial stock price reactions are much larger than the long-term reactions. The magnitude of the decline varies across companies. For instance, TEPCO's *CARs* are more negative than All's *CAR*s for all windows. Figure 1 draws the *CAR*s after the accident, confirming that the *CARs* are exceptionally negative for TEPCO.

[Table 3 & Figure 1 here]

The *CAR*s of Tohoku Electric Power Co. (shown as Victim), which was also hit by the earthquake, are below -30%, which is less negative than TEPCO's *CAR*s, but more negative than the *CAR*s of the other 9 electric power utilities (shown as Non-Victim). Both Figure 2 and Table 3 show that *CAR*s are more negative for Victim than for Non-Victim samples. In addition, Table 4 shows that Victim's mean *CAR*s are significantly more negative than Non-Victim's mean *CAR*s at the 1% level for both windows. This is consistent with H_2 and justifies our elimination of Tohoku Electric Power from the samples for the subsequent analyses. Note that for the Non-Victim sample *CAR* (0, 2) is -9.3%, *CAR* (0, 30) is -16.8%, and *CAR* (0, 137) is -20.1%. The magnitude of the negative reactions is far larger than that observed in the TMI and Chernobyl accidents.

[Figure 2 & Table 4 here]

After excluding Tohoku Electric Power Co., we then investigate whether the possession of nuclear power plants affected stock price reactions by comparing the *CAR*s between NPP and Non-NPP samples. Both Figure 2 and Table 3 show that NPP's *CAR*s are more negative for the NPP sample than for the Non-NPP sample. In addition, Table 4 shows that NPP's mean *CAR*s are significantly more negative than Non-NPP's mean *CAR*s at the 1% level for both windows. This is consistent with H_3 and means that stock prices of electric power utilities that own nuclear power plants declined more sharply than those of companies that do not own nuclear power plants. This result also justifies our elimination of the Non-NPP sample, that is, OEPC and J-Power, from the samples for the subsequent analyses.

After excluding the Non-NPP samples, we next examine whether the dependency on nuclear power generation affected stock price reactions by comparing the *CAR*s between the LN and Non-LN samples. Figure 3 shows that the *CAR*s are not much different between these two groups until June, though LN's *CAR*s declined more sharply than did Non-LN's *CAR*s after that. Table 4 also shows that the mean *CAR*s (0, 30) are not significantly different between the LN and Non-LN samples, though the mean *CAR* (0, 137) is significantly more negative for the LN sample than for the Non-LN sample at the 5% level. This is consistent with H_4 and indicates that the possibility of suspension of nuclear power plants increased later, which is likely to decrease the future value of companies with a major commitment to nuclear power generation.

[Figure 3 here]

With regard to the differences in types of nuclear power reactors, we first study whether the reactor age affected stock price responses by comparing *CAR*s between Old and Non-Old samples. Figure 4 shows that the *CAR*s are not much different between the two groups. In addition, Table 3 shows that *CAR* (0, 2) and *CAR* (0, 30) are more negative for the Old sample than for the Non-Old sample, though *CAR* (0, 137) is less negative for the Old sample than for the Non-Old sample. Table 4 shows that the differences in mean *CAR*s between the two groups are not significant for either window. These results indicate that investors did not consider that the use of old nuclear power reactors would lower the future firm value.

[Figure 4 here]

Last, we examine whether use of the Mark 1 nuclear reactor container affected stock price reactions by comparing the *CAR*s between the Mark 1 and Non-Mark 1 samples. Figure 4 shows that the *CAR*s are not much different between the two groups before June 2011, while Mark 1's *CAR*s are less negative than those of Non-Mark 1 after that. In addition, Table 3 presents that Mark 1's *CAR*s are less negative than Non-Mark 1's *CAR*s for all windows, while Table 4 shows that the mean *CAR* (0, 137) is significantly less negative for the Mark 1 sample than for the Non-Mark 1 sample at the 1% level. These results indicate that investors did not consider that the use of the Mark 1 nuclear reactor container would lower the future firm value.

Our analyses of *CAR*s can be summarized as follows. First, the stock prices of utilities that own nuclear power plants declined more sharply after the accident than did those of other utilities. However, whether companies use old nuclear power reactors or the Mark 1 nuclear reactor container did not decrease stock prices of electric power utilities more largely than those of the other electric power utilities. These results indicate that investors are sensitive to the reduction of future profits by reducing the use of nuclear power generation. However, whether companies employ nuclear power reactors similar to those used in Fukushima Daiichi nuclear power station does not tend to affect stock prices.

The latter result may partly be the result of the small number of public announcements regarding these issues. Table 1 shows that the number of Nikkei-related newspaper articles that contain the words "duration years" is only 7 from March 11 to September 30, 2011, while the number of articles containing the words "Mark 1" is only 2 during the same period. These numbers are quite small, compared, for example, to the number of articles containing the words "suspension" or "inspection" of nuclear power reactors. This indicates that average investors may not have been aware of the importance of these issues.

4.2. Empirical results regarding stability of the market model

The previous subsection shows that, on average, stock prices of electric power utilities declined after the Fukushima Daiichi nuclear accident. The negative market reactions indicate a one-time loss when the parameters of the asset pricing process utilized in determining stock prices are stable. However, when the parameters have shifted during the post-Fukushima period, negative market reactions suggest a loss caused by structural changes in society. To check this point, we first compare the parameters between the pre- and post-Fukushima periods.

[Table 5 here]

Table 5 presents a comparison of risk-related variables between the pre- and post-accident periods. α and β in Table 5 corresponds to $\hat{\alpha}_p$ and $\hat{\beta}_p$ in equation (2), respectively. α is a measure of idiosyncratic risk, which is similar to *CAR*. Because we discussed *CAR* in the previous subsection, we omit discussion of α here. β is a measure of systematic risk, which reflects a structural relationship between each portfolio's returns and market returns. Because we are interested in whether there are structural changes in systematic risk between the pre- and post-Fukushima periods, our analysis focuses on β. We also include variances of stock returns as a measure of total risk, which should reflect both systematic and idiosyncratic risks.

For the portfolio of all electric power utilities, β increased from 0.26 in the pre-period to 0.96 (a 3.66-fold increase) in the short-term post-period (0, 30) and then to 0.88 (a 3.38-fold increase) in the long-term post-period (0, 137).[7] This indicates that systematic risk increased immediately after the accident and then remained at a similar level with a small decrease. Because we are interested in the structural changes in parameters, we focus on the long-term change of β after the initial adjustment, that is, between the pre-period and the long-term post-period (0, 137) in the subsequent discussion.

The increase of β is particularly large for TEPCO and Tohoku Electric Power Co. (=Victim in Table 5), which were hit by the earthquake. For TEPCO, β increased by 7.81 times, while for Victim, β increased by 6.09 times. Without these two companies, the increase of β is moderate, with β increasing by 2.60 times for the Non-Victim sample. These results indicate that systematic risks increased dramatically for companies hit by the earthquake.

Among Non-Victim companies, the increase of β is slightly larger for the NPP sample than for the Non-NPP sample. For the NPP sample, β increased by 2.75 times, while for the Non-NPP sample, β increased by 2.25 times. Although the differences between the two groups are small, these results indicate that systematic risks increased for companies that own nuclear power plants, because these companies are likely to be affected negatively by the possible suspension of nuclear power plants in the future.

We next examine how systematic risks are affected by characteristics of companies that own nuclear power plants. Among NPP companies, the increase of β is slightly larger for the LN sample than for the Non-LN sample, for the Old sample than for the Non-Old sample, and for the Non-Mark 1 sample than for the Mark 1 sample. For the LN sample, β increased 2.84-fold, while for the Non-LN samples, β increased 2.51-fold. For the Old sample, β increased 2.85-fold, while for the Non-Old sample, β increased 2.61-fold, while for the Mark 1 sample, β increased 2.48-fold, while for the Non-Mark 1 sample, β increased 2.79-fold.

[7] To eliminate the period of price adjustment, we conduct the same analysis by using the alternative post-Fukushima period (31, 137) by regarding the first 30 trading days as the period of adjustment. The results are presented in Appendix, which shows that estimated parameters in the post-Fukushima period become smaller than those in Table 5, but the patterns are almost consistent.

These results indicate that systematic risks increased more for companies with a major commitment to nuclear power generation, for those with old nuclear reactors, and for those without the Mark 1 nuclear reactor container than for the other companies, although the differences between the two groups are quite small and may not signify an important difference. The results for the LN sample and Old sample seem to be reasonable, because such companies are likely to experience a reduction of future cash flow. Although the results for the Mark 1 sample may not be consistent with the prediction, this is partly because the Mark 1 sample consists only of one electric power utility.

Table 5 provides simple evidence that β shifts between the pre- and post-Fukushima periods. We next look at variances of returns, which represent total risks. For the portfolio of all electric power utilities, variances increased from 0.89 in the pre-period to 9.43 (a 10.62-fold increase) in the short-term post-Fukushima period (0, 30) and then to 5.09 (a 5.73-fold increase) in the long-term post-Fukushima period (0, 137). This indicates that total risks increased immediately after the accident and then became smaller later. Because our interest lies in the structural changes, we focus on the long-term change of variances between the pre-period and the long-term post-Fukushima period (0, 137).

The increase of variances is particularly large for TEPCO and Tohoku Electric Power Co., which were hit by the earthquake. For TEPCO, variances increased 38.29-fold, while for Tohoku Electric Power Co., variances increased 11.05-fold. Without these two companies, the increase of variances is relatively moderate, with variances increasing 4.69-fold for the Non-Victim sample. These results indicate that total risks increased more remarkably for companies hit by the earthquake than for the other companies.

Among the Non-Victim samples, the increase of variances is larger for the NPP sample than for the Non-NPP sample. For the NPP sample, variances increased 5.12-fold, while for the Non-NPP sample, variances increased 3.01-fold. These results indicate that the increase of total risks is larger for companies that own nuclear power plants. Among the Non-NPP sample, we do not obtain consistent results regarding a major commitment to nuclear power generation, as the increase of variance is larger for the LN sample than for the Non-LN sample in the short-term post-Fukushima period (0, 30), while it is smaller for the LN sample than for the Non-LN sample in the long-term post-Fukushima period (0, 137).

The increase of variances is slightly larger for the Old sample than for the Non-Old sample. For the Old sample, variances increased by 5.24 times, while for the

Non-Old sample, variances increased 4.93-fold. This result indicates that total risks increased more for companies with old nuclear reactors, although the difference between the two groups is quite small and may not signify an important difference.

With this comparison we do not obtain evidence that the use of the Mark 1 nuclear reactor container increases total risks. For the Mark 1 sample, variances increased 4.80-fold, while for the Non-Mark 1 sample, variances increased 5.15-fold. Similar to the results with systematic risk, the results for the Mark 1 sample may not be consistent with the prediction, possibly because the Mark 1 sample consists of only one electric power utility.

Finally, the rightmost column of Table 5 presents the results of Chow tests, in which March 11, 2001 is set as a break point. For all portfolios of electric power utilities, the F-statistics are significant at the 1% level, indicating there is a structural change between the pre- and the post-Fukushima periods.

5. Sensitivity analysis

To check the robustness of our results, we conduct the same analyses by setting a longer pre-Fukushima period of 533 trading days between January 6, 2009, and March 10, 2011. The results are presented in Tables 6 to 8, which provide similar results to those in Tables 3 to 5. Thus, we confirm that our main results are not changed by setting a different pre-Fukushima period.

[Tables 6-8 here]

We also conduct additional tests on H_5 by using different characteristics of nuclear power reactors. Here we focus on two characteristics similar to the Fukushima Dai-ichi power station, namely, the use of plutonium thermal (PN) and boiling water reactors (BWR). The other characteristics include no use of plutonium thermal (Non-PN) and the use of pressurized water reactors (PWR).[8] Figure 5 shows that *CAR*s for the PN, Non-PN, BWR, and PWR samples differ very little from one another. In fact, Table 9 shows that both the mean *CAR* (0, 30) and *CAR* (0, 137) are not significantly different from zero between the PN and Non-PN samples and between the BWR and PWR samples for two estimation windows, except for one. These results are consistent with our prior results indicating that whether companies employ nuclear power reactors

[8] As explained in the notes of Figure 5, the PN sample consists of 3 companies: Kansai, Shikoku, and Kyushu, while the Non-PN sample consists of 4 companies: Chubu, Chugoku, Hokuriku, and Hokkaido. The BWR sample consists of 3 companies: Chubu, Chugoku, and Hokuriku, while the PWR sample consists of 4 companies: Kansai, Shikoku, Kyushu, and Hokkaido.

similar to those used at the Fukushima Daiichi nuclear power station does not tend to decrease stock prices.

[Figure 5 & Table 9 here]

Last, we conduct alternative tests on H_6 by estimating the following market model (1)' for each utility and then compare whether the mean of estimated parameters for each group is different between the pre- and post-Fukushima periods:

$$R_{i,t} = \alpha_i + \beta_i R_{m,t} + \varepsilon_{i,t} \qquad (1)'.$$

The results are presented in Table 10. Note that the mean *CAR* here is calculated across utilities in the same group, and that the group containing only one utility, such as Victim and Mark 1, cannot be examined. Table 10 confirms that for all groups but one (Non-NPP), differences in mean β and variances are significantly different from zero between the pre- and post-Fukushima periods, indicating that both systematic and total risks increased after the Fukushima accident.[9]

[Table 10 here]

6. Summary and concluding remarks

In this paper we investigate the effect of the accident at the Fukushima Daiichi nuclear power station, which is owned by TEPCO, on stock prices of the other electric power utilities in Japan. We report the following findings. First, stock prices of the firm hit by the earthquake declined more sharply than did those of the other firms. Second, stock prices of the firms that own nuclear power plants declined more sharply than did those of firms without nuclear power plants. In contrast, shareholders of firms did not seem to care about whether electric power utilities own nuclear power reactors similar to those at the Fukushima Daiichi.

These results indicate that investors expected that the recent changes in the attitudes of the public and of the regulation would increase the costs of power generation, suggesting the reduction of future cash flow of the firms dependent on nuclear power generation. However, investors were less sensitive to potential risks that

[9] We also conduct the Wilcoxon signed-rank test, which confirms that differences in mean β and variances for the All, Non-Victim, and NPP groups are significantly different from zero at the 1% level between the pre- and post-Fukushima periods. This test cannot be conducted for the other groups due to their small sample size.

might cause another disastrous accident by using nuclear power reactors similar to those at the Fukushima Daiichi power station.

To determine whether the market reactions were structurally changed after the Fukushima accident, we examine the stability of the parameters of the market model before and after the accident. We observe that the absolute value of beta and variances increased after the accident, indicating the increase of both systematic and total risks in the post-accident period. The shift in the parameters also suggests that negative *CAR*s are not merely caused by one-time losses but by structural changes in society and the regulation that could increase the costs of power generation. We then conduct breakpoint Chow tests, which provide evidence of structural changes in the relationship between stock returns of nine electric power utilities and those of TOPIX. The exception is OEPC, which does not own a nuclear power plant.

We confirm that our results are robust in the sense that they are not sensitive to specific estimation windows. Although we acknowledge that the small number of listed electric power utilities in Japan may have limited our ability to assess the stability of the market model to some extent, we believe that our study is of interest not only to researchers but also to investors and regulators of electric power utilities.

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Appendix: Comparison of risk-related variables based on the alternative post-Fukushima period (Unit: %)

	Comparison of parameters							
	(-250, -1)			(31, 137)				
	α	β (a)	Var (b)	α	β (e)	(e)/(a)	Var (f)	(f)/(b)
All	-0.030	0.261	0.888	-0.019	0.723	(2.77)	3.793	(4.27)
TEPCO	-0.057	0.230	1.085	-0.163	1.595	(6.94)	27.230	(25.10)
Victim	-0.014	0.273	0.894	-0.010	0.784	(2.87)	4.976	(5.56)
Non-Victim	-0.023	0.265	0.890	-0.022	0.641	(2.42)	3.262	(3.67)
NPP	-0.015	0.264	0.889	-0.031	0.668	(2.53)	3.578	(4.02)
Non-NPP	-0.075	0.262	1.125	0.089	0.453	(1.73)	2.412	(2.14)
LN	-0.007	0.260	0.898	-0.044	0.667	(2.57)	3.447	(3.84)
Non-LN	-0.036	0.275	0.917	0.002	0.668	(2.43)	4.135	(4.51)
Old	-0.017	0.258	0.885	0.000	0.652	(2.53)	3.617	(4.09)
Non-Old	-0.012	0.273	0.920	-0.073	0.688	(2.52)	3.619	(3.93)
Mark 1	-0.031	0.275	0.934	0.056	0.689	(2.51)	3.621	(3.88)
Non-Mark 1	-0.012	0.263	0.894	-0.046	0.664	(2.53)	3.607	(4.03)

Figure 1: Cumulative abnormal returns for Japanese electric power utilities
The estimation window is set at 250 trading days between March 4, 2010, and March 10, 2011.

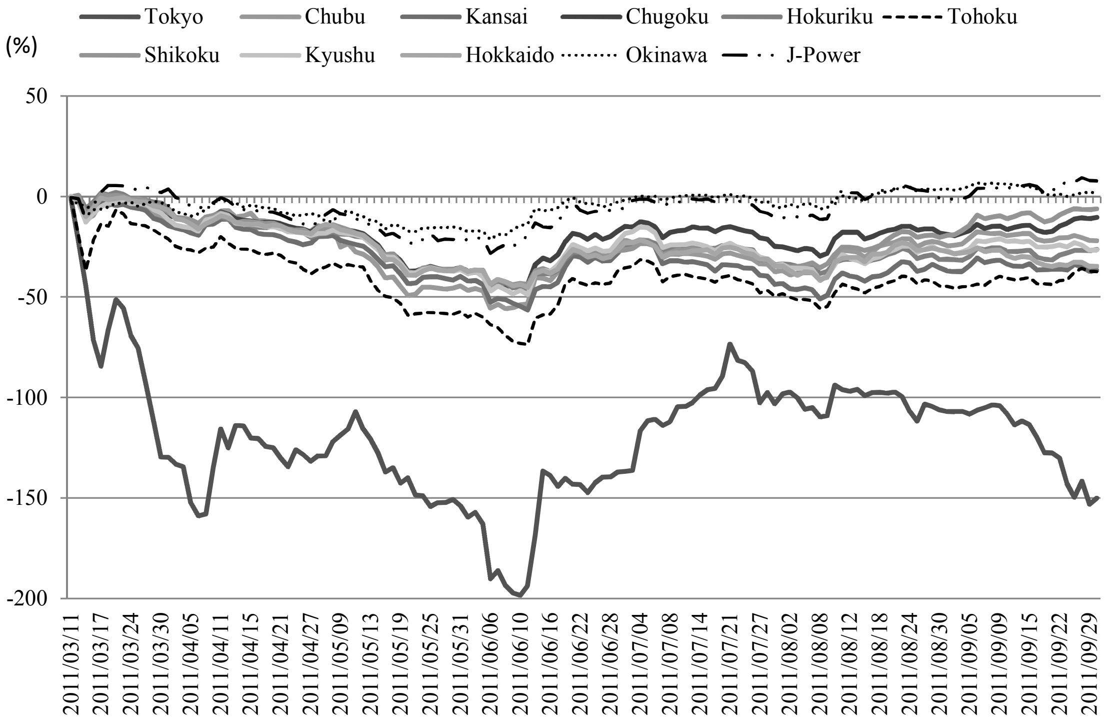

Figure 2: *CAR*s for the Victim, Non-Victim, NPP, and Non-NPP samples

- The estimation window is set at 250 trading days between March 4, 2010, and March 10, 2011.
- The Victim sample consists of Tohoku Electric Power Co.
- The Non-victim sample consists of 9 electric power utilities: Chubu, Kansai, Chugoku, Hokuriku, Shikoku, Kyushu, Hokkaido, Okinawa, and J-Power.
- The NPP sample consists of 7 electric power utilities: Chubu, Kansai, Chugoku, Hokuriku, Shikoku, Kyushu, and Hokkaido.
- The Non-NPP sample consists of Okinawa Electric Power Co. and J-Power.

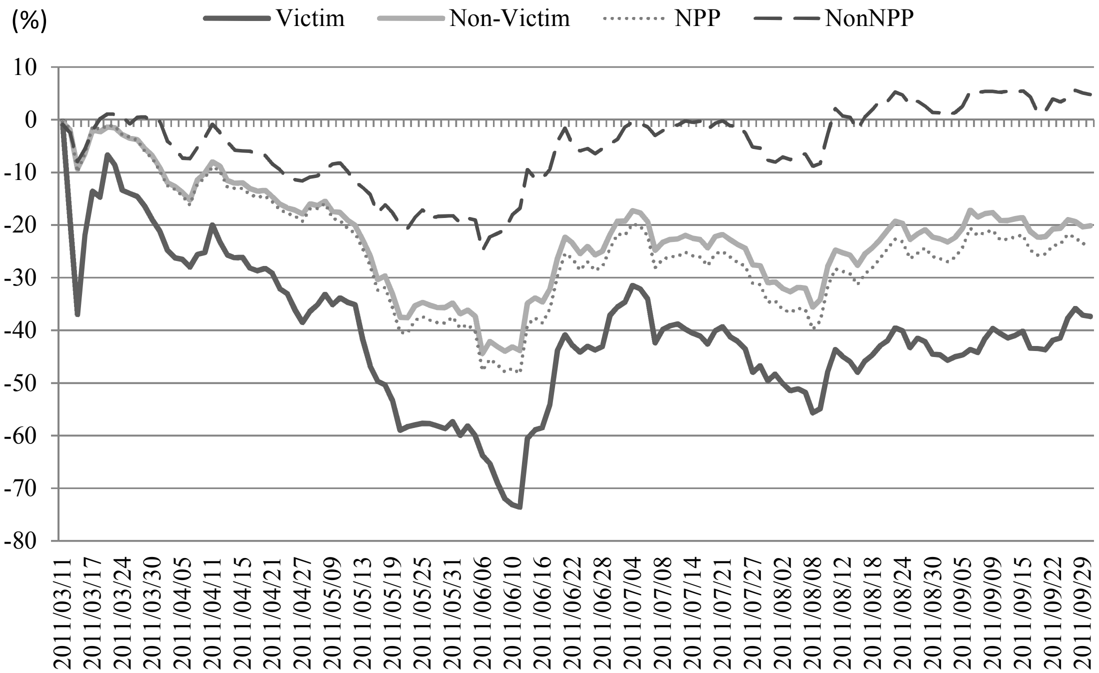

Figure 3: *CAR*s for the LN and Non-LN samples

- The estimation window is set at 250 trading days between March 4, 2010, and March 10, 2011.
- The LN sample consists of 5 companies: Kansai, Hokuriku, Shikoku, Kyushu, and Hokkaido.
- The Non-LN sample consists of Chubu and Chugoku.

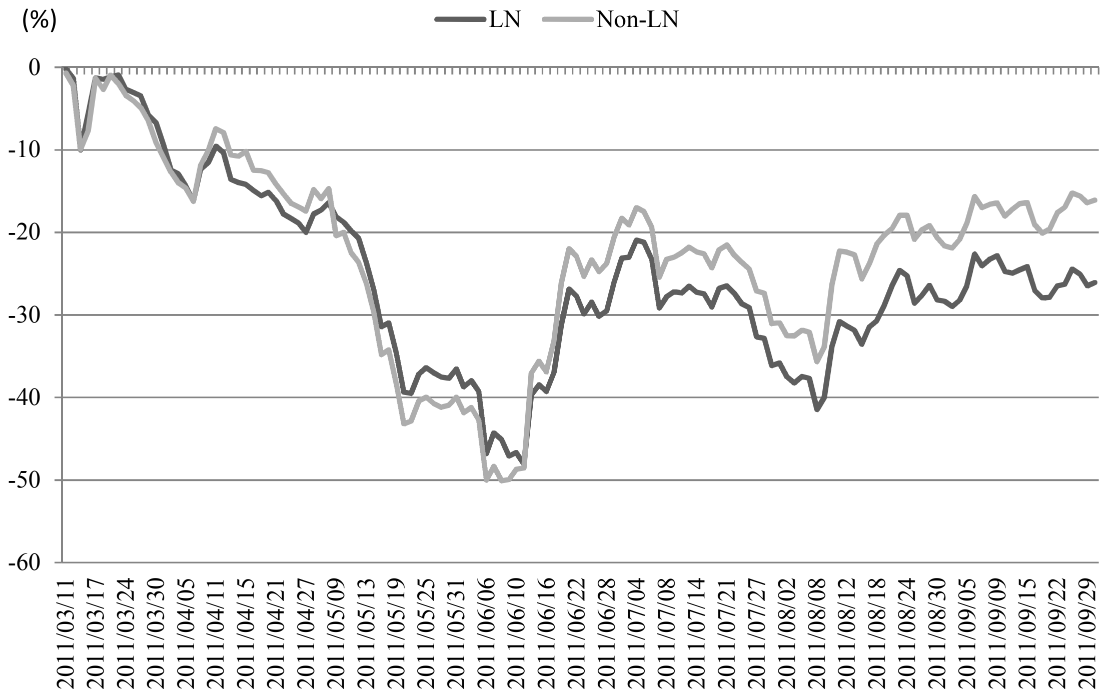

Figure 4: *CAR*s for the Mark 1, Non-Mark 1, Old, and Non-Old samples

- The estimation window is set at 250 trading days between March 4, 2010, and March 10, 2011.
- The Mark 1 sample consists of Chugoku.
- The Non-Mark 1 sample consists of 6 companies: Kansai, Shikoku, Kyushu, Chubu, Hokuriku, and Hokkaido.
- The Old sample consists of 4 companies: Kansai, Chugoku, Shikoku, and Kyushu.
- The Non-Old sample consists of 3 companies: Chubu, Hokuriku, and Hokkaido.

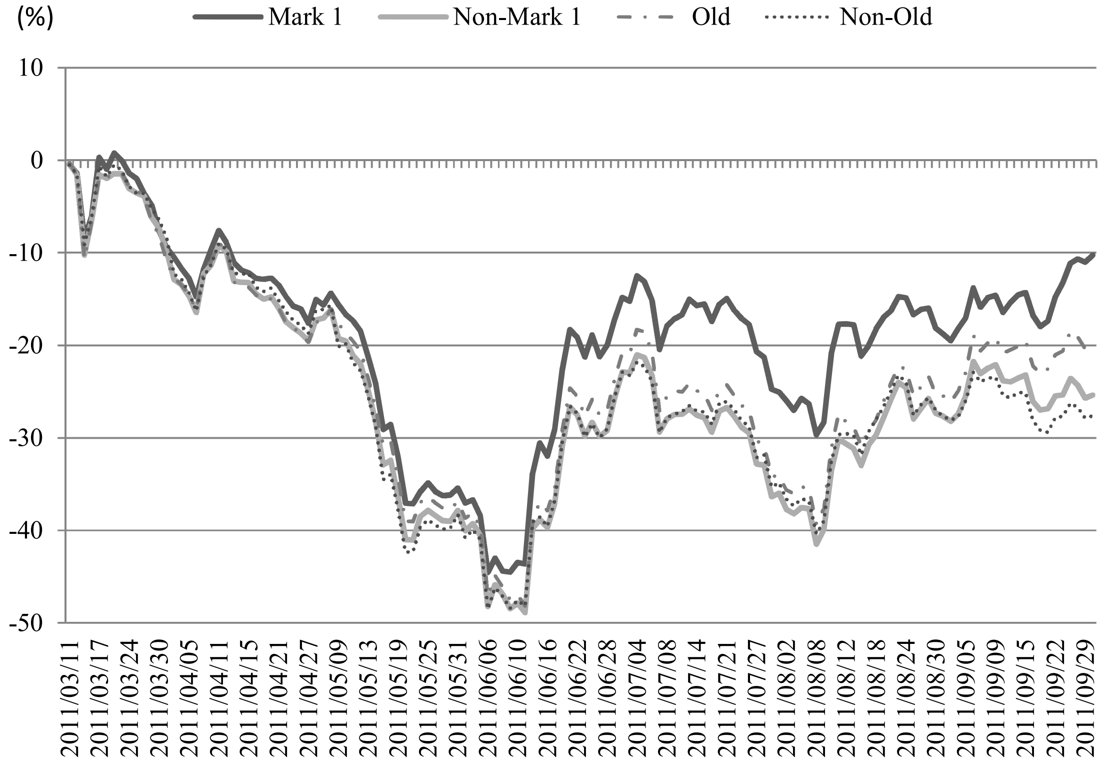

Figure 5: *CAR*s for the PN, Non-PN, BWR, and PWR samples

- The estimation window is set at 250 trading days between March 4, 2010, and March 10, 2011.
- The PN sample consists of 3 companies: Kansai, Shikoku, and Kyushu.
- The Non-PN sample consists of 4 companies: Chubu, Chugoku, Hokuriku, and Hokkaido.
- The BWR sample consists of 3 companies: Chubu, Chugoku, and Hokuriku.
- The PWR sample consists of 4 companies: Kansai, Shikoku, Kyushu, and Hokkaido.

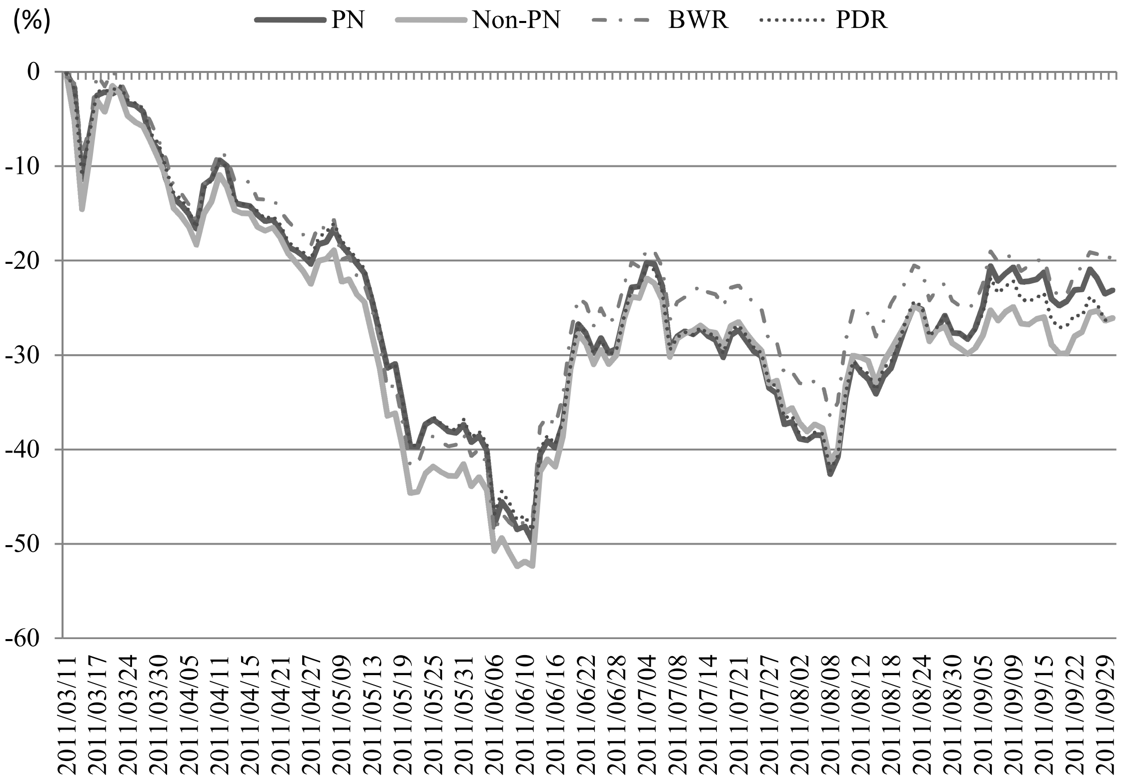

Table 1: Newspaper articles related to the electric power utilities

Keywords \ Periods	(0, 30) Mar. 11 - Apr. 25	(31, 137) Apr. 26 - Sep. 30
Nuclear Power Generation	2,522	6,228
Nuclear Power Reactor	466	752
(+) Durable years	2	5
(+) Decomissioning	30	50
(+) Suspension	176	339
(+) Inspection	56	80
Mark 1	2	0

Source: Nikkei Telecom.

Table 2: Portfolios of sample firms

Company name	Victim / Non-Victim	NPP / Non-NPP	LN / Non-LN	Old / Non-Old	Mark 1 / Non-Mark 1
Tokyo	(Victim)	(NPP)	(LN)	(Old)	(Mark 1)
Tohoku	Victim	(NPP)	(LN)	(Non-Old)	(Mark 1)
Chubu	Non-Victim	NPP	Non-LN	Non-Old	Non-Mark 1
Kansai	Non-Victim	NPP	LN	Old	Non-Mark 1
Chugoku	Non-Victim	NPP	Non-LN	Old	Mark 1
Hokuriku	Non-Victim	NPP	LN	Non-Old	Non-Mark 1
Shikoku	Non-Victim	NPP	LN	Old	Non-Mark 1
Kyushu	Non-Victim	NPP	LN	Old	Non-Mark 1
Hokkaido	Non-Victim	NPP	LN	Non-Old	Non-Mark 1
Okinawa	Non-Victim	Non-NPP	-	-	-
J-Power	Non-Victim	Non-NPP	-	-	-

Notes:

1. Victim means an electric power utility that was stricken by the Great East earthquake and tsunami together with TEPCO, while other electric power utilities were not hit by the natural disaster and thus are labeled as Non-Victim.
2. NPP means an electric power utility that owns nuclear power plants, while other companies do not own a nuclear power plant and thus are labeled as Non-NPP.
3. LN means an electric power utility with a major commitment to nuclear energy based on the criterion that at least 20 percent of the total power generation must be nuclear, while other companies are labeled as Non-LN.
4. Old means an electric power utility that uses old nuclear power plants that were built in the 1970s, while other companies using non-old nuclear power plants, which were built after 1980, are labeled as Non-Old.
5. Mark 1 means an electric power utility that uses the Mark 1 nuclear reactor design, while other companies without Mark 1 are labeled as Non-Mark 1.

Table 3: Cumulative abnormal returns (Unit: %)

	(0, 2)		(0, 30)		(0, 137)	
	CAR	SCAR	CAR	SCAR	CAR	SCAR
All	-15.294	-(12.08) ***	-27.783	-(6.94) ***	-30.935	-(3.62) ***
TEPCO	-45.290	-(26.89) ***	-125.948	-(23.64) ***	-149.996	-(13.18) ***
Victim	-37.018	-(29.06) ***	-33.084	-(8.21) ***	-37.335	-(4.34) ***
Non-Victim	-9.339	-(7.36) ***	-16.755	-(4.18) ***	-20.098	-(2.34) **
NPP	-9.993	-(7.88) ***	-17.786	-(4.44) ***	-23.220	-(2.71) ***
Non-NPP	-7.988	-(4.60) ***	-11.039	-(2.01) **	4.795	(0.41)
LN	-10.016	-(7.75) ***	-18.307	-(4.48) ***	-26.071	-(2.99) ***
Non-LN	-9.935	-(7.50) ***	-16.485	-(3.94) ***	-16.092	-(1.80) *
Old	-10.658	-(8.44) ***	-18.157	-(4.55) ***	-19.928	-(2.34) **
Non-Old	-9.106	-(6.83) ***	-17.292	-(4.10) ***	-27.609	-(3.07) ***
Mark 1	-8.479	-(6.22) ***	-15.788	-(3.66) ***	-10.267	-(1.11)
Non-Mark 1	-10.245	-(8.00) ***	-18.119	-(4.47) ***	-25.378	-(2.93) ***

Notes: 1. *** and ** indicate statistical significance at the 1% and 5% levels, respectively.
2. The estimation window is set at 250 trading days between March 4, 2010, and March 10, 2011.

Table 4: Comparison of mean *CAR*s (Unit: %)

		250-day estimation window	
		(0, 30)	(0, 137)
Victim	Mean CAR (a)	-21.868	-40.611
Non-Victim	Mean CAR (b)	-8.761	-22.011
	Difference (a-b)	-13.107	-18.600
	t-stat	-7.551 ***	-12.977 ***
NPP	Mean CAR (a)	-9.280	-24.547
Non-NPP	Mean CAR (b)	-3.766	-4.937
	Difference (a-b)	-5.514	-19.610
	t-stat	-4.680 ***	-17.254 ***
LN	Mean CAR (a)	-9.428	-25.417
Non-LN	Mean CAR (b)	-8.911	-22.372
	Difference (a-b)	-0.517	-3.045
	t-stat	-0.376	-2.252 **
Old	Mean CAR (a)	-9.551	-23.832
Non-Old	Mean CAR (b)	-8.919	-25.500
	Difference (a-b)	-0.631	1.668
	t-stat	-0.447	1.250
Mark 1	Mean CAR (a)	-8.071	-18.863
Non-Mark 1	Mean CAR (b)	-9.481	-25.494
	Difference (a-b)	1.411	6.632
	t-stat	1.021	5.153 ***

Notes: 1. The estimation window is set at 250 trading days between March 4, 2010, and March 10, 2011.
2. *** and ** indicate statistical significance at the 1% and 5% levels, respectively.
3. Mean *CAR* is equal to the *CAR* divided by the number of days in the post-period.
4. t-stat is calculated by using the mean *CAR*, variances of *CAR*, and the number of days in the post-Fukushima period.

Table 5: Comparison of risk-related variables and Chow test (Unit: %)

	Comparison of parameters													Chow test
	(-250, -1)			(0, 30)					(0, 137)					(-250, 137)
	α	β (a)	Var (b)	α	β (c)	(c)/(a)	Var (d)	(d)/(b)	α	β (e)	(e)/(a)	Var (f)	(f)/(b)	F-stat
All	-0.030	0.261	0.888	-0.725	0.958	(3.66)	9.431	(10.62)	-0.172	0.883	(3.38)	5.085	(5.73)	14.468 ***
TEPCO	-0.057	0.230	1.085	-3.655	1.835	(7.98)	88.937	(81.96)	-0.937	1.794	(7.81)	41.549	(38.29)	9.274 ***
Victim	-0.014	0.273	0.894	-0.541	2.142	(7.86)	26.840	(30.01)	-0.101	1.660	(6.09)	9.880	(11.05)	42.188 ***
Non-Victim	-0.023	0.265	0.890	-0.436	0.705	(2.67)	7.320	(8.23)	-0.113	0.688	(2.60)	4.176	(4.69)	7.847 ***
NPP	-0.015	0.264	0.889	-0.449	0.749	(2.84)	7.903	(8.89)	-0.122	0.725	(2.75)	4.551	(5.12)	8.490 ***
Non-NPP	-0.075	0.262	1.125	-0.317	0.657	(2.51)	6.708	(5.96)	0.003	0.589	(2.25)	3.381	(3.01)	4.841 ***
LN	-0.007	0.260	0.898	-0.450	0.771	(2.97)	8.007	(8.92)	-0.132	0.739	(2.84)	4.472	(4.98)	9.598 ***
Non-LN	-0.036	0.275	0.917	-0.446	0.696	(2.53)	7.976	(8.69)	-0.098	0.691	(2.51)	5.000	(5.45)	5.588 ***
Old	-0.017	0.258	0.885	-0.454	0.774	(3.00)	8.151	(9.21)	-0.098	0.736	(2.85)	4.639	(5.24)	8.829 ***
Non-Old	-0.012	0.273	0.920	-0.442	0.717	(2.63)	7.722	(8.39)	-0.154	0.711	(2.61)	4.538	(4.93)	7.692 ***
Mark 1	-0.031	0.275	0.934	-0.428	0.665	(2.42)	7.437	(7.96)	-0.052	0.680	(2.48)	4.484	(4.80)	6.067 ***
Non-Mark 1	-0.012	0.263	0.894	-0.452	0.763	(2.91)	8.042	(8.99)	-0.134	0.733	(2.79)	4.604	(5.15)	8.778 ***

Note: *** indicates statistical significance at the 1% level.

Table 6: Cumulative abnormal returns based on an alternative estimation window (Unit: %)

	(0, 2)		(0, 30)		(0, 137)	
	CAR	SCAR	CAR	SCAR	CAR	SCAR
All	-14.588	-(9.10) ***	-26.911	-(5.31) **	-27.811	-(2.57) ***
TEPCO	-44.507	-(23.63) ***	-125.546	-(21.08) ***	-149.116	-(11.72) ***
Victim	-35.904	-(19.86) ***	-31.584	-(5.52) ***	-31.838	-(2.61) ***
Non-Victim	-8.682	-(5.38) ***	-15.774	-(3.09) ***	-16.417	-(1.51)
NPP	-9.353	-(5.84) ***	-16.715	-(3.30) ***	-19.106	-(1.77) *
Non-NPP	-7.295	-(3.38) ***	-10.943	-(1.61)	4.385	(0.30)
LN	-9.270	-(5.77) ***	-17.026	-(3.35) ***	-21.126	-(1.95) *
Non-LN	-9.559	-(5.63) ***	-15.939	-(2.97) ***	-14.055	-(1.22)
Old	-9.917	-(6.07) ***	-17.087	-(3.31) ***	-15.941	-(1.45)
Non-Old	-8.601	-(5.30) ***	-16.220	-(3.16) ***	-23.326	-(2.13) **
Mark 1	-7.940	-(4.65) ***	-14.729	-(2.73) ***	-6.086	-(0.53)
Non-Mark 1	-9.588	-(5.94) ***	-17.046	-(3.34) ***	-21.276	-(1.95) *

Notes: 1. *** and ** indicate statistical significance at the 1% and 5% levels, respectively.
2. The estimation window is set at 533 trading days between January 6, 2009, and March 10, 2011.

Table 7: Comparison of mean *CAR*s based on an alternative estimation window (Unit: %)

		(0, 30)		(0, 137)	
Victim	Mean CAR (a)	-20.881		-37.711	
Non-Victim	Mean CAR (b)	-8.131		-20.081	
	Difference (a-b)	-12.750		-17.630	
	t-stat	-7.613	***	-12.805	***
NPP	Mean CAR (a)	-8.630		-22.402	
Non-NPP	Mean CAR (b)	-8.558		-5.050	
	Difference (a-b)	-0.072		-17.352	
	t-stat	-0.063		-15.742	***
LN	Mean CAR (a)	-8.630		-22.842	
Non-LN	Mean CAR (b)	-8.558		-21.302	
	Difference (a-b)	-0.072		-1.540	
	t-stat	-0.055		-1.177	
Old	Mean CAR (a)	-8.858		-21.738	
Non-Old	Mean CAR (b)	-8.277		-23.288	
	Difference (a-b)	-0.581		1.551	
	t-stat	-0.428		1.211	
Mark 1	Mean CAR (a)	-7.428		-16.697	
Non-Mark 1	Mean CAR (b)	-8.806		-23.353	
	Difference (a-b)	1.378		6.656	
	t-stat	1.039		5.323	***

Notes: 1. The estimation window is set at 533 trading days between January 6, 2009, and March 10, 2011.
2. *** and ** indicate statistical significance at the 1% and 5% levels, respectively.
3. Mean *CAR* is equal to the *CAR* divided by the number of days in the post-period.
4. t-stat is calculated by using mean the *CAR*, variances of *CAR*, and the number of days in the post-period.

Table 8: Comparison of risk-related variables and Chow test based on an alternative pre-Fukushima period (Unit: %)

	Comparison of parameters													Chow test
	(-533, -1)			(0, 30)					(0, 137)					(-533, 137)
	α	β (a)	Var (b)	α	β (c)	(c)/(a)	Var (d)	(d)/(b)	α	β (e)	(e)/(a)	Var (f)	(f)/(b)	F-stat
All	-0.048	0.296	1.362	-0.725	0.958	(3.23)	9.431	(6.92)	-0.172	0.883	(2.98)	5.085	(3.73)	26.321 ***
TEPCO	-0.058	0.272	1.513	-3.655	1.835	(6.75)	88.937	(58.78)	-0.937	1.794	(6.60)	41.549	(27.46)	23.324 ***
Victim	-0.047	0.327	1.495	-0.541	2.142	(6.54)	26.840	(17.96)	-0.101	1.660	(5.07)	9.880	(6.61)	83.532 ***
Non-Victim	-0.046	0.296	1.367	-0.436	0.705	(2.38)	7.320	(5.35)	-0.113	0.688	(2.32)	4.176	(3.05)	12.997 ***
NPP	-0.041	0.294	1.360	-0.449	0.749	(2.54)	7.903	(5.81)	-0.122	0.725	(2.46)	4.551	(3.35)	14.823 ***
Non-NPP	-0.067	0.300	1.711	-0.317	0.657	(2.19)	6.708	(3.92)	0.003	0.589	(1.96)	3.381	(1.98)	5.763 ***
LN	-0.038	0.295	1.362	-0.450	0.771	(2.61)	8.007	(5.88)	-0.132	0.739	(2.51)	4.472	(3.28)	16.288 ***
Non-LN	-0.048	0.293	1.413	-0.446	0.696	(2.37)	7.976	(5.65)	-0.098	0.691	(2.36)	5.000	(3.54)	10.493 ***
Old	-0.041	0.294	1.376	-0.454	0.774	(2.63)	8.151	(5.92)	-0.098	0.736	(2.51)	4.639	(3.37)	14.989 ***
Non-Old	-0.040	0.295	1.372	-0.442	0.717	(2.43)	7.722	(5.63)	-0.154	0.711	(2.41)	4.538	(3.31)	13.840 ***
Mark 1	-0.058	0.299	1.420	-0.428	0.665	(2.22)	7.437	(5.24)	-0.052	0.680	(2.27)	4.484	(3.16)	10.541 ***
Non-Mark 1	-0.038	0.294	1.366	-0.452	0.763	(2.60)	8.042	(5.89)	-0.134	0.733	(2.50)	4.604	(3.37)	15.289 ***

Note: *** indicates statistical significance at the 1% level.

Table 9: Comparison of mean *CAR*s for the PN, Non-PN, BWR, and PWR samples (Unit: %)

		250-day estimation window		533-day estimation window	
		(0, 30)	(0, 137)	(0, 30)	(0, 137)
PN	Mean CAR (a)	-10.044	-25.488	-9.335	-23.418
Non-PN	Mean CAR (b)	-11.339	-27.195	-10.628	-24.855
	Difference (a-b)	1.296	1.706	1.293	1.437
	t-stat	0.878	1.255	0.911	1.101
BWR	Mean CAR (a)	-8.642	-23.295	-8.169	-21.572
PWR	Mean CAR (b)	-9.759	-25.486	-8.940	-23.025
	Difference (a-b)	1.117	2.191	0.771	1.453
	t-stat	0.793	5.218 ***	0.569	1.134

Note: *** indicates statistical significance at the 1% level.

Table 10: Tests for mean differences of risk-related variables

	Pre(-250, -1)			Post(0, 137)			Post(0, 137) - Pre(-250, -1)								
	α	β	Var	α	β	Var	α			β			Var		
	Mean	Mean	Mean	Mean	Mean	Mean	Mean	t-stat		Mean	t-stat		Mean	t-stat	
All	-0.030	0.261	1.042	-0.725	0.958	17.190	-0.695	-2.362	**	0.696	4.338	***	16.149	2.188	**
Non-Victim	-0.028	0.264	1.053	-0.419	0.729	8.146	-0.391	-14.400	***	0.465	9.046	***	7.093	16.802	***
NPP	-0.013	0.231	0.851	-0.107	0.635	4.267	-0.094	-3.761	***	0.403	15.199	***	3.416	13.244	***
Non-NPP	-0.075	0.262	1.336	0.003	0.589	3.936	0.078	1.546		0.327	1.987		2.600	2.607	
LN	-0.007	0.260	0.974	-0.132	0.739	4.732	-0.126	-3.722	**	0.479	12.370	***	3.757	12.927	***
Non-LN	-0.036	0.275	0.968	-0.098	0.691	5.237	-0.062	-1.200		0.416	8.115	**	4.269	7.666	**
Old	-0.017	0.258	0.951	-0.098	0.736	4.886	-0.081	-1.905	*	0.478	10.267	***	3.935	12.173	***
Non-Old	-0.012	0.273	1.002	-0.154	0.711	4.864	-0.142	-6.724	**	0.439	13.451	***	3.862	6.803	**
Non-Mark 1	-0.012	0.263	0.979	-0.134	0.733	4.942	-0.122	-4.317	***	0.470	14.572	***	3.963	12.508	***

Notes:

1. *** and ** indicate statistical significance at the 1% and 5% levels, respectively.
2. α and β correspond to the estimated parameters, $\hat{\alpha}_i$ and $\hat{\beta}_i$ based on the following market model:

$$R_{i,t} = \alpha_i + \beta_i R_{m,t} + \varepsilon_{i,t},$$

where $R_{i,t}$ is the return of the electric power utility i on day t.