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Abstract

This paper examines the effect of the Fukushima nuclear disaster on bond risk premia of Japanese electric power companies. We examine whether the accident affects or not more sharply companies owning nuclear power plants, companies with a major commitment of nuclear power generation, and companies owning the same type of nuclear power reactors as the one operated at the Fukushima Daiichi station. At the same time, we examine how spread of short-term and long-term government bond yields, market return, coupon of bond, and maturity affect bond risk premia of electric power companies.

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1 Introduction

The Fukushima nuclear disaster occurred after the East Japan great earthquake and tsunami, occurred on March 11, 2011. Three of the six nuclear reactors failed at the Fukushima Daiichi nuclear power stations owned by Tokyo electric power company (TEPCO). More than three years have passed but some people evacuated from the Fukushima nuclear disaster are forced not to return to their homes because of the danger of contamination with radioactivity and areas near the Fukushima Daiichi nuclear power stations are still seriously affected in their way of life. On the other hand, many nuclear power plants are being constructed and planned to be constructed in the future all over the world. Thus it is important to assess the damage of the Fukushima nuclear disaster. There exist a number of works studying the effect of the Fukushima nuclear disaster on stock prices of electric power companies (Betzer et al. (2011), Ferstl et al. (2012), Kawashima and Takeda (2012), Lopatta and Kaspereit (2012), and Serita and Xu (2012) among others). They report significantly negative effects on Japanese power companies in periods of the first couple of days and subsequent several months after the disaster. The aim of this paper is to investigate the effect of the Fukushima nuclear disaster on the risk premia of electric power companies in Japan. So far, to the best of our knowledge, no studies exist which investigate the effect of the disaster on bonds of electric power companies. Bonds are an important category of financial commodities and they have characteristics different from stocks. Studying the effect on the risk premia of electric power companies helps to assess the damage of the Fukushima nuclear disaster in a different way. We study the effect of the Fukushima nuclear disaster on bond risk premia of electric power companies in Japan. Not all companies issue bonds although they have stocks sold in the stock market. Our study deals with companies issue bonds. As a result, we focus on 10 electric power companies in Japan. They are local monopolies supply electricity in 10 local areas, after which they are named, i.e., Tokyo (TEPCO), Chubu, Kansai, Chugoku, Hokuriku, Tohoku, Shikoku, Kyushu, Hokkaido, and Okinawa. They supply more than 99 % of electricity used in Japan (cf., Yamaguchi (2007)).

Kawashima and Takeda (2012) examine stocks of 9 electric power companies except TEPCO and a company called J-Power to investigate whether the victim (Tohoku), which was hit by the East Japan great earthquake and tsunami, suffers more compared to non-victim 8 companies, whether companies own nuclear power plants are more severely affected than companies do not own nuclear power plants, whether companies with a major committement to nuclear energy suffer more than companies with a small commitment to nuclear energy, and whether companies use the same type of nuclear power reactors as the one operated at the Fukushima Daiichi station are more affected than companies do no use. We follow Kawashima and Takeda (2012) to investigate the same issues in bond risk premia of electric power companies in Japan. We use weekly data to avoid missing data in some of daily bond risk premia data. As a preceding study on bond risk premia, we remark the work of Barrett et al. (1986) investigated the effect of the three mile island accident on utility bond risk premia. Our aim is similar to that of Barrett et al. (1986).

The paper is organized as follows. In Section 2, we provide and explain data of bond risk premia. In Section 3, we present models and explain estimation and testing results. In Section 4, we provide concluding comments.

2 Data

We use weekly data from April 3, 2009 to November 29, 2013. The number of observations is 244; there is 101 observations before March 11, 2011 and 141 observations from March 11, 2011 to November 29, 2013. This is mainly because we try to include as many TEPCO data as possible; some bonds of TEPCO have missing observations so that they are excluded from our data. Risk premium of a bond is a yield of the bond minus a yield of a government bond whose maturity is closest to that of the bond in question. Some bonds do not have corresponding government bonds and they are not included in our sample. There are 103 bonds in our data; 4, 22, 11, 12, 12, 13, 1, 14, 11, and 3 respectively for TEPCO, Chubu, Kansai, Chugoku, Hokuriku, Tohoku, Shikoku, Kyushu, Hokkaido, and Okinawa. We remark J-power, which was included in the work of Kawashima and Takeda (2012), does not issue any bonds so that it is not included in our analysis.

To show characteristics of data, we show figures of risk premia of 10 electric power companies. They are given in Figures 1-10. Risk premium of a company in Figures 1-10 is computed as an equally weighted average of risk premia of all the bonds of that company included in the sample.

The risk premium of TEPCO increases most after the Fukushima accident in all of the electric power companies. The magnitude of the increase of risk premium after the Fukushima accident is by far the largest for TEPCO; it increases upto nuearly 10 %, which is more than 10 times as large as the highest level for other companies. The risk premium all increases in other companies. In particular, the increase of risk premium after the accident is high for Kansai, Tohoku, Shikoku, and Kyushu. While all the companies have their risk premia up after the accident, the peak of the increase of risk premia differs among the companies. Each company faces a different local environment for its activity so that each company has its own reason for variation in its risk premium. The risk premium of TEPCO has its peak in November, 2011 and then declines sharply after that. Risk premia for other companies have much smaller increases compared to for TEPCO. Yet, their variation appears to look rather dramatic. Risk premium for Chubu is suddenly up after the accident and then has a shape like a plateau although it declines in the last months in the sample. Risk premium of Kansai jumps after the accident but has its peak in January 2013, which is rather late, and then declines afterwards. Kansai's risk premium peak has its value 0.876, which is the biggest in 9 companies except TEPCO. Chugoku and Hokuriku have their risk premia quite similar to Chubu. Tohoku has risk premium similar to Kansai and peaks at the same week of January 11, 2013 as Kansai. Its peak value is 0.754, which is the second highest in 9 electric power companies except TEPCO. Shikoku has a peculiar risk premium which appears to have a kind of an upward trend although declines at the end. Risk premium of Kyushu has a pattern similar to Kansai and Tohoku. It has a peak at the week of January 11, 2013, the same as Kansai and Tohoku. Hokkaido has a risk premium curve similar to Chubu, Chugoku, and Hokuriku. Lastly Okinawa has a riks premium jumped after the accident and has a shape of a plateau. Therefore we can describe Okinawa's risk premium has a pattern similar to Chubu, Chugoku, Hokuriku, and Hokkaido. It has the smallest increase among all the companies. This can be attributed to the fact Okinawa is the only company does not own nuclear power plants in 10 electric power companies. Therefore, there are four patterns in the risk premium curve of 10 companies after the accident. The first one is the pattern of TEPCO has a shape of a mountain with a unique peak at an early time. The second one is the patten of Chubu, Chugoku, Hokuriku, Hokkaido, and Okinawa with a shape of a plateau. The third one is the pattern of Kansai, Tohoku, and Kyushu has a shape of a mountain with a peak at the week of January 11, 2013. The fourth one is the pattern of Shikoku has an upward trend. In Figure 11, term, i.e., spread of short-term (3-month government bond) and long-term government bond (10-year government bond) yields, is shown to have a downward trend in the sample. In Figure 12, price of the Topix Index is shown in a graph. It has an upward trend after Mr. Shinzo Abe became a prime minister in Japan in December 2012.

In Figures 13-20, we compare two risk premia before and after the Fukushima accident. For example, we compare risk premia of TEPCO and other 9 companies (Non-TEPCO) in Figure 13. Risk premium of TEPCO is an average of risk premia of 4 bonds of TEPCO while that of Non-TEPCO is mean of 9 averages of risk premia for 9 companies where an average of risk premia for each company is mean of risk premia of all the bonds of that company. In Figure 14, we compare two risk premia of Victim, i.e., TEPCO and Tohoku, and Non-Victim (8 companies except TEPCO and Tohoku). We can see dramatic contrast in the two figures; risk premium of TEPCO jumped right after the accident and peaked early after the accident and risk premium of Victim has a similar pattern although the scale of a vertical axis in Figure 13 is twice as much as that in Figure 14. When we exclude TEPCO in the category of Non-Victim, we can see non-negligible difference of two risk premia of Victim and Non-Victim in Figure 15, which is much smaller than that in Figure 14. We can see the smaller difference of the two categories in Figure 15 not only in the two curves but also in the difference of two scales of the vertical axis in Figures 14-15. Figure 16 presents two risk premia of companies with nuclear power plants including TEPCO (NPPWT) and companies[1] without nuclear power plants (Non-NPPWT) while Figure 17 presents two risk premia of companies with nuclear power plants excluding TEPCO (NPP) and companies without

[1] Okinawa is the only company without nuclear power plants in 10 electric power companies in Japan.

nuclear power plants (Non-NPP). As in Figures 14 and 15, the difference of the two risk premia is more distinct in Figure 16 than in Figure 17. When TEPCO is included in risk premium of a category, then risk premium of the category increases after the Fukushima accident because of the higher risk premium of TEPCO. In Figure 18, risk premium of companies with a major commitment to nuclear energy (LN) does not deviate from that with a minor commitment to nuclear energy (Non-LN) until year 2013 when the former takes higher values than the latter. We follow Kawashima and Takeda (2012) to make companies with a major commitment to nuclear energy composed of 5 companies, i.e., Kansai, Hokuriku, Shikoku, Kyushu, and Hokkaido, and while companies with a minor commitment to nuclear energy composed of 2 companies, i.e., Chubu and Chugoku. In other words, the two categories of LN and Non-LN are based on 7 companies excluding TEPCO, Tohoku, and Okinawa. In Figure 19, risk premia of companies with old (OLD) and non-old power plants (Non-OLD) are similar to those of LN and Non-LN in Figure 18; risk premium of OLD is similar to that of Non-OLD until year 2013 when the former jumps compared to the latter. Again the categories of OLD and Non-OLD are based on the 7 comapnies as in LN and Non-LN categories and OLD companies are composed of Kansai, Chugoku, Shikoku, and Kyushu while Non-OLD companies are composed of Chubu, Hokuriku, and Hokkaido. Lastly, in Figure 20, risk premium of companies with Mark 1 type nuclear power plants does not differ from that of companies with Non-Mark 1 type nuclear power plants until year 2013 when the former is lower than the latter, which seems rather counter-intuitive. The categories of Mark 1 and Non-Mark 1 are obtained from the 7 companies as in those of LN and Non-LN adn Mark 1 companies are composed of Chugoku while Non-Mark 1 are composed of the rest of the 7 companies. Since the category of Mark 1 is composed of only Chugoku, the better performance of Mark 1 in the year 2013 may not be attributed to Mark 1 type nuclear power plants. Instead, it may be attributed to local demand and supply conditions of Chugoku compared to those of the rest of the 7 companies.

In the following we show summary statistics for 10 electric power companies before and after the disaster. In addition, we show summary statistics for spread of short-term (3-month government bond) and long-term government bond (10-year government bond) yields, which we call it term. They are given at Tables 1-11.

The difference of mean and median before and after the accident in the summary statistics is huge for TEPCO; it is respectively about 13 times for mean and 21 times for median after the accident as much as that before the accident. The difference of mean and median after the accident is about 3 times as much as that before the accident for Chubu, Chugoku, Hokuriku, Kyushu, Hokkaido. For Kansai, Tohoku, and Shikoku, it is after the accident more than 3 times as much as that before the accident. On the other hand, it is not so much different before and after the accident for Okinawa; its main reason appears to be because Okinawa is the only electric power company does not own a nuclear power plant and thus least affected by the accident. For term, i.e., spread of a 10-year government bond yield and a 3-month government yield, mean and median are smaller after the accident than before the accident; they are, after the accident, about 60 % of those before the accident.

3 Estimation Results

In this section we estimate models for bond risk premia of electric power companies in Japan during the period before and after the Fukushima nuclear accident. We first estimate the following model given by

$$\begin{aligned} R_{ii_jt} &= \sum_{j=1}^{10} D_j\alpha_j + \lambda_1 dum1_{ii_jt} + \beta_1 term_t + \beta_2 term_t \times dum1_{ii_jt} + \gamma_1 tepco_{ii_jt} + \\ &\quad + \gamma_2 victim_{ii_jt} + \gamma_3 NPP_{ii_jt} + \delta_1 coupon_{ii_jt} + \delta_2 maturity_{ii_jt} + \varepsilon_{ii_jt} \qquad (1) \end{aligned}$$

where R_{ii_jt} denotes the return of the i_j-th bond of the i-th company at time t, D_j denotes the dummy variable of being 1 if j = i and 0 otherwise ($j = 1, \cdots, 10$), $term_t$ denotes spread of a yield of 10 year govenment bond and a yield of 3 month govenment bond, $dum1_{ii_jt}$ denotes the dummy variable of being 1 if t is after March 11, 2011 and 0 otherwise, $tepco_{ii_jt}$ denotes the dummy variable of being 1 if the company is TEPCO and time is after March 11, 2011, $victim_{ii_jt}$ denotes the dummy variable of the victim of the Fukushima nuclear accident besides TEPCO, i.e., Tohoku electric power company, which is 1 if the company is Tohoku and time is after March 11, 2011, NPP_{ii_jt} denotes the dummy variable of being 1 if the company owns nuclear power plants and time is after March 11, 2011, and 0 otherwise, $coupon_{ii_jt}$ denotes the coupon of the i_j-th bond for the company i expressed in percentage, i.e., 100 × coupon, and $maturity_{ii_jt}$ denotes the maturity of the i_j-th bond of the i-th company measured by the number of months from March 2011 till month of its maturity date. Data for the model are panel data and we estimate the model as a fixed-effects model. A parameter α_i denotes a fixed-effect of the i-th company; $\alpha_1, \alpha_2, \alpha_3, \alpha_4, \alpha_5, \alpha_6, \alpha_7, \alpha_8, \alpha_9$, and α_{10} are respectively the fixed-effect for TEPCO, Chubu, Kansai, Chugoku, Hokuriku, Tohoku, Shikoku, Kyushu, Hokkaido, and Okinawa. Estimation results for the above model are given at Table 12.

The estimate of the fixed-effect dummy variable α_i appears to reflect the magnitude of the effect of the Fukushima disaster on bond risk premia; it is 0.527 for TEPCO, the largest among 10 electric power companies while it is less than 0.2 for the rest of the companies except for α_7, the fixed-effect of Shikoku. The fixed-effect parameter α_i is 10 % significant only for TEPCO and Kansai while insignificant for the rest of the companies. The structural change parameter λ_1 estimate of the Fukushima accident is 0.276 and 10 % significant. This implies the Fukushima accident made higher bond risk premia of electric power companies. The term coefficient β_1 estimate is positive and 1 % significant but the corresponding estimate after the Fukushima accident is not significant. The TEPCO dummy variable estimate of γ_1 is highly significant and the largest of all the coefficient estimates, 4.039, and its t-value is also the biggest of all the t-values. The victim coefficient estimate of γ_2 for Tohoku is small, i.e., 0.108, and 1 % significant while the NPP dummy variable estimate of γ_3 is 0.195 and also 1 % significant. The t-values presented in Table 12 are double-cluster robust t-values, where clustering is a two-way with respect to both company and time (cf., e.g., Cameron et al. (2011), Petersen (2009), and Thompson (2011)). Although we have obtained other t-value estimates based on variance estimates obtained assuming zero serial correlation and either zero or non-zero contemporaneous correlations between different companies, one way cluster robust t-values with respect to company and/or time, etc, which are not presented here, the double-cluster robust t-values presented at Table 12 seem to be the most appropriate judging from their t-values for the TEPCO, victim, NPP, and structural change dummy variables. We only present double-cluster t-values as t-values in the estimation results given in this paper.

TABLES 12-13 ABOUT HERE

Meanwhile, after Mr. Shinzo Abe was elected as a prime minister in Japan in December 2012, his so-called *Abenomics* economic policy has vitalized the Japanese economy, particularly stock markets, so that we try to introduce the effect of *Abenomics* on the bond risk premia of electric power companies in Japan. To do so, we introcude the market return and structural change dummy variable of *Abenomics* economic policy. Thus we next consider the following model;

$$\begin{aligned} R_{ii_jt} \;=\; & \sum_{j=1}^{10} D_j\alpha_j + \lambda_1 dum1_{ii_jt} + \lambda_2 dum2_{ii_jt} + \beta_1 term_t + \beta_2 term_t \times dum1_{ii_jt} \\ & +\beta_3 term_t \times dum2_{ii_jt} + \beta_4 R_{Mt} + \beta_5 R_{Mt} \times dum1_{ii_jt} + \beta_6 R_{Mt} \times dum2_{ii_jt} \\ & +\gamma_1 tepco_{ii_jt} + \gamma_2 victim_{ii_jt} + \gamma_3 NPP_{ii_jt} + \delta_1 coupon_{ii_jt} \\ & +\delta_2 maturity_{ii_jt} + \varepsilon_{ii_jt} \end{aligned} \tag{2}$$

where $dum2_{ii_jt}$ denotes a dummy variable of being 1 if time t is ever since January 11, 2013 and 0 otherwise and R_{Mt} denotes return of the TOPIX Index at time t as the market return. We regard January 11, 2013 as the beginning of *Abenomics* in our study. Estimation results for this model are also given at Table 12. The model (1) and (2) are estimated using all the 10 electric power companies including TEPCO in Japan. The estimates and t-values in the model (2) are quite similar to those in the model (1) except for the estimates of the structural change parameter λ_1 and λ_2 of the Fukushima accident and *Abenomics* respectively, the estimates of β_2 and β_3, the effect of term after the two structural changes, and the estimates of β_4, β_5, and β_6, coefficients associated with the market return over an entire period and after the two strucural changes. The estimate of the structural change parameter λ_1 is 0.276 and 10 % significant in the model (1) while it increases to 0.462 and highly significant in the model (2) when the structural change parameter λ_2 of *Abenomics* is added to the model (2). The estimate of the structural change parameter λ_1 increases by introduction of the strucural change parameter λ_2 of *Abenomics* ecnomic policy, whose estimate is negative and highly significant. We consider the positive estimate of λ_1 implies bond risk premia of electric power companies become higher after the Fukushima accident while the negative estimate of λ_2 implies they become lower after *Abenomics* economic policy. We remark term is always significant in three periods in the model (2); during an entire period, after the Fukushima accident, and after *Abenomics* economic policy. On the other hand, the magnitude of the estimate of the market return is small and not significant in all of the three periods. As shown in the summary statistics and figures of bond risk premia in Section 2, the estimate of the TEPCO dummy coefficient is quite large compared to other coefficient estimates and highly significant in both the model (1) and (2). Coupon and maturity are both insignificant in the model (1) and (2).

Following Kawashima and Takeda (2012), we also want to examine whether the victim of the Great East earthquake and tsunami, besides TEPCO, which consists only of Tohoku electric power company, was affected by the Fukushima accident compared to other 8 electric power companies, which were not hit by the natural disaster and labelled as Non-Victim. The above hypothesis is tested using the following model given below;

$$\begin{aligned} R_{ii_jt} &= \sum_{j=2}^{10} D_j\alpha_i + \lambda_1 dum1_{ii_jt} + \lambda_2 dum2_{ii_jt} + \beta_1 term_t + \beta_2 term_t \times dum1_{ii_jt} \\ &\quad + \beta_3 term_t \times dum2_{ii_jt} + \beta_4 R_{Mt} + \beta_5 R_{Mt} \times dum1_{ii_jt} + \beta_6 R_{Mt} \times dum2_{ii_jt} \\ &\quad + \gamma_2 Victim_{ii_jt} + \delta_1 coupon_{ii_jt} + \delta_2 maturity_{ii_jt} + \varepsilon_{ii_jt} \qquad (3) \end{aligned}$$

where $Victim_{ii_jt}$ denotes a dummy variable of being 1 if the company is Tohoku and time is after March 11, 2011, and 0 otherwise. Bonds for nine electric power companies except TEPCO are used to estimate and test the above model (3). We want to examine the effect of the accident on the victim, excluding TEPCO which was damaged enormously by the accident. This is because TEPCO may affect the estimate of the coefficient of the victim if it is included in the data. The fixed-effect dummy variable α_i estimate has changed in the model (3) compared to that in the model (1) and (2). All of the fixed-effect dummy variable estimates are now negative except for Kansai, which is positive but not significant. They are 10 % significant for Hokuriku and 1 % significant for Shikoku and Okinawa. The fixed-effect dummy variable estimate is -0.200 and -0.129 respectively for Shikoku and Okinawa, which are two largest negative numbers. This Okinawa's estimate makes sense given the relatively mild damage on Okinawa as shown in the figure and summary statistics given in the previous section. The structural change parameter λ_1 and λ_2 are respectively positive and negative and both are 1 % significant. They are not so different from those in the model (2). The term and market return estimates, i.e., the estimates of $\beta_i(i = 1, \cdots, 6)$, are not so different from those in the model (2), although β_5, the coefficient of the market return after the Fukushima accident, is 1 % significant and β_6, the coefficient of the market return after *Abenomics* economic policy, is negative and 10 % significant in the model (3). The negative estimate of β_6 implies bond risk premia becomes lower after *Abenomics* since the market return increases after *Abenomics* started. The victim dummy variable estimate for γ_2 is 0.114, which is small compared to the TEPCO dummy estimate 4.039 in the model (1) and (2), but it is highly significant. Coupon is highly significant but its estimate is a small negative number, -0.014. Maturity becomes positive and 1 % significant but very small, i.e., 0.001. Coupon and maturity are not significant in the model (1) and (2). Coupon and maturity become both significant in the model (3) when TEPCO data are excluded but they are insignificant in the model (1) and (2) when TEPCO data are included. We may state that enormous damage of TEPCO changed the impications of the two variables of coupon and maturity in the model (3).

Next we want to estimate the effect of use of nuclear power plants along with other factors with 8 electric power companies excluding TEPCO and Tohoku. In other words, we want to estimate and test the following model with 8 electric power companies;

$$
\begin{aligned}
R_{ii_jt} &= \sum_{j\neq 1,6} D_j\alpha_j + \lambda_1 dum1_{ii_jt} + \lambda_2 dum2_{ii_jt} + \beta_1 term_t + \beta_2 term_t \times dum1_{ii_jt} \\
&\quad + \beta_3 term_t \times dum2_{ii_jt} + \beta_4 R_{Mt} + \beta_5 R_{Mt} \times dum1_{ii_jt} + \beta_6 R_{Mt} \times dum2_{ii_jt} \\
&\quad + \gamma_3 NPP_{ii_jt} + \delta_1 coupon_{ii_jt} + \delta_2 maturity_{ii_jt} + \varepsilon_{ii_jt}. \qquad (4)
\end{aligned}
$$

Among 8 electric power companies, only Okinawa does not own nuclear power plants. The fixed-effect dummy variable estimate in the model (4) is similar to that in the model (3) except Okinawa, where the estimate is -0.017, much smaller in absolute value than that in the model (3), and insignificant. The structural change parameters of λ_1 and λ_2 are not so different from those in the model (3). Also the term and market return coefficient estimates, i.e., the estimates of $\beta_i(i = 1, \cdots, 6)$, are similar to those in the model (3). NPP dummy variable is positive and highly significant. Therefore, companies own nuclear power plants have higher risk premia than those do not own nuclear power plants. The estimate of γ_3 is pretty large, indicating a serious negative effect of the use of nuclear power plants. Estimates for coupon and maturity are also similar to those in the model (3) and both significant.

Then we want to examine whether a major commitment of nuclear energy, defined by more than 20 % of dependence[2] on nuclear power, makes a difference compared to other electric power companies whose dependence on nuclear power is less than 20 %, among 7 electric power companies except TEPCO, Tohoku, and Okinawa. Furthermore, we also investigate whether use of old type of nuclear power plants built in 1970s and the Mark 1 type nuclear power reactor, both of which are characteristics of the Fukushima Daiichi station, has significant effects on risk premia compared to use of non-old type of nuclear power plants built after 1980 and the nuclear reactor container other than the Mark 1 type. In order to examine these effects, we estimate the following model;

$$\begin{aligned} R_{ii_jt} &= \sum_{j\neq 1,6,10} D_j\alpha_j + \lambda_1 dum1_{ii_jt} + \lambda_2 dum2_{ii_jt} + \beta_1 term_t + +\beta_2 term_t \times dum1_{ii_jt} \\ &\quad +\beta_3 term_t \times dum2_{ii_jt} + \beta_4 R_{Mt} + \beta_5 R_{Mt} \times dum1_{ii_jt} + \beta_6 R_{Mt} \times dum2_{ii_jt} \\ &\quad +\gamma_4 LN_{ii_jt} + \gamma_5 OLD_{ii_jt} + \gamma_6 MARK1_{ii_jt} + \delta_1 coupon_{ii_jt} \\ &\quad +\delta_2 maturity_{ii_jt} + \varepsilon_{ii_jt} \qquad (5) \end{aligned}$$

where LN_{ii_jt}, OLD_{ii_jt}, and $MARK1_{ii_jt}$ are 3 dummy variables of being 1 when the company has a major commitment of nuclear energy, nuclear power plants built in 1970s, and the Mark 1 type nuclear reactor respectively and when time is after March 11, 2011 and 0 otherwise. The fixed-effect dummy variable estimates in absolute value become smaller in the model (5) than in the model (4) except Shikoku and Kyushu. This seems reasonable since companies in the model (5) becomes more homogenious than in the model (4). Among the fixed-effect dummy variable estimates, only Shikoku is highly significant and Hokuriku is 10 % significant. The structural change parameter estimate of λ_1 becomes larger in the model (5) than in the model (4) while that of λ_2 is similar

[2]See Kawashima and Takeda (2012). Companies with a major commitment of nuclear energy are composed of TEPCO, Kansai, Hokuriku, Tohoku, Shikoku, Kyushu, and Hokkaido. On the other hand, companies with a minor commitment fo nuclear energy are composed of Chubu and Chugoku.

to the one in the model (4). They are both highly significant. The term and market return parameter estimates remain to be similar to those in the model (4). LN, a dummy variable of more dependence on nuclear energy, is positive and 5 % significant. Therefore, companies with a major committement to nuclear energy have risk premia higher and hence suffer more than companies with a minor commitment. OLD, a dummy of old type of nuclear power plants built in 1970s, is positive and 1 % significant. Hence companies use old type nuclear power plants have risk premia higher than those do not use. On the other hand, the Mark 1 dummy variable estimate is negative and 1 % significant. Thus, companies use the Mark 1 type reactor container similar to the Fukushima Daiichi station have risk premia lower than those do not use. This is similar to the finding of Kawashima and Takeda (2012) regarding the Mark 1 dummy variable. As for coupon and maturity, the results are similar to those in the model (4).

4 Concluding comments

We have examined the effect of the Fukushima accident on bond risk premia of electric power companies along with the effect of other factors. The impact of the Fukushima accident is huge on the risk premium of the TEPCO bond. The damage on the the TEPCO bond is not so large as that on the TEPCO stock by the difference in nature of the bond and stock but still quite large. On the other hand, the damage on Tohoku's risk premium is not significant when we include TEPCO in the sample but significant when we exclude TEPCO from the sample. Companies with nuclear power plants have risk premia higher than those without nuclear power plants. Companies with a major commitment to nuclear energy also have risk premia higher than those with a minor commitment to nuclear energy. Companies use old type nuclear power plants have risk premia higher than those do not use. These conclusions are similar to findings in the studies of stock returns of electric power companies of early periods such as Kawashima and Takeda (2012). On the other hand, comapanies use the Mark 1 type reactor have risk premium lower than companies do not use. This is counter-intuitive since one expects companies use the Mark 1 type reactor will suffer more than those do not use the Mark 1 type reactor. However, this is similar to the result of Kawashima and Takeda (2012). It may not be attributed to characteristics of the Mark 1 type reactor because companies use the Mark 1 type reactor are composed of the only one company, i.e., Chugoku. Instead it may be due to underlying local economic and social conditions including demand and supply of Chugoku. We have obtained estimation results using the cluster-robust variance estimates of the LSE of the model parameters in order to take into account clustering with respect to company and time. Other variance estimates of the LSE do not provide reliable estimates since clustering of residuals of the same company and/ or the same time appears to exist.

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Figure 1: Bond risk premium of TEPCO

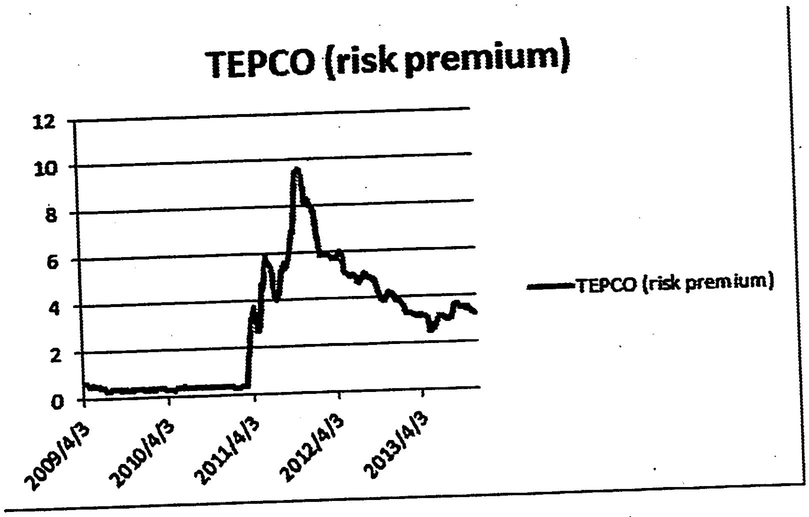

Figure 2: Bond risk premium of Chubu Electric Power

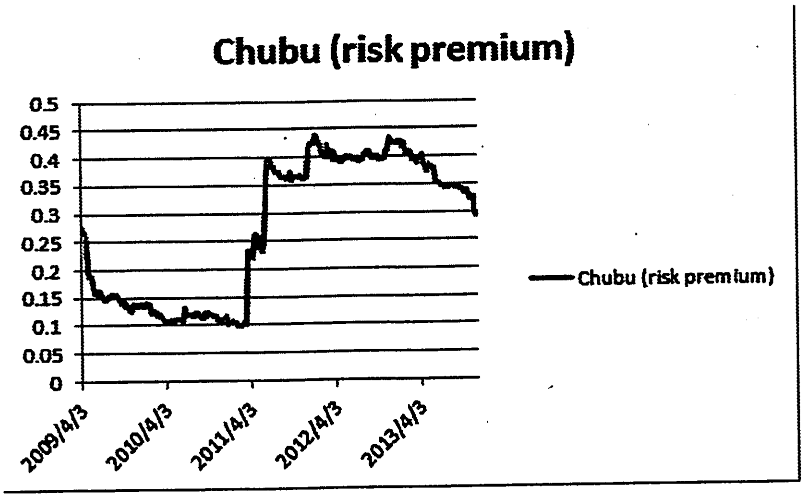

Figure 3: Bond risk premium of Kansai Electric Power

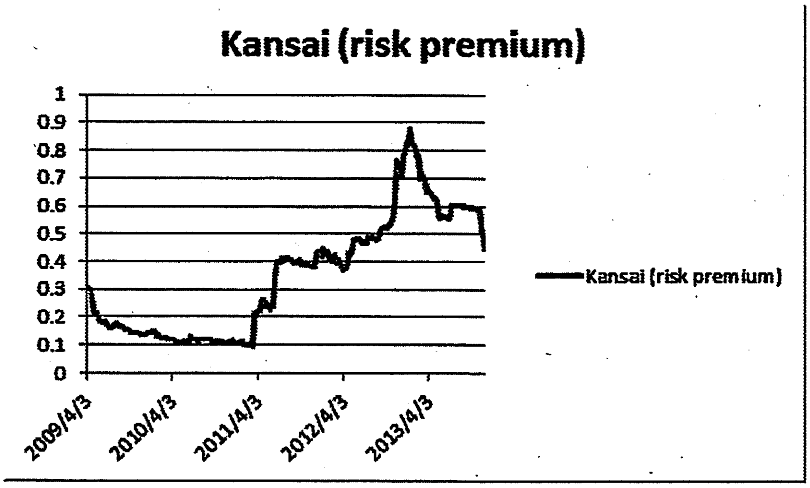

Figure 4: Bond risk premium of Chugoku Electric Power

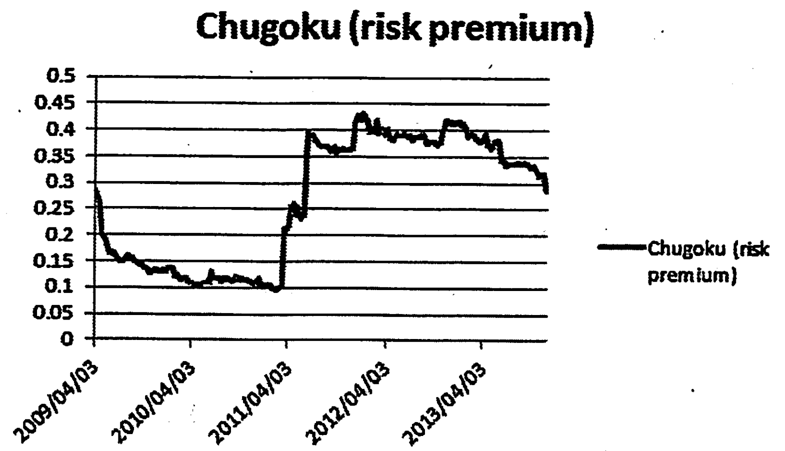

Figure 5: Bond risk premium of Hokuriku Electric Power

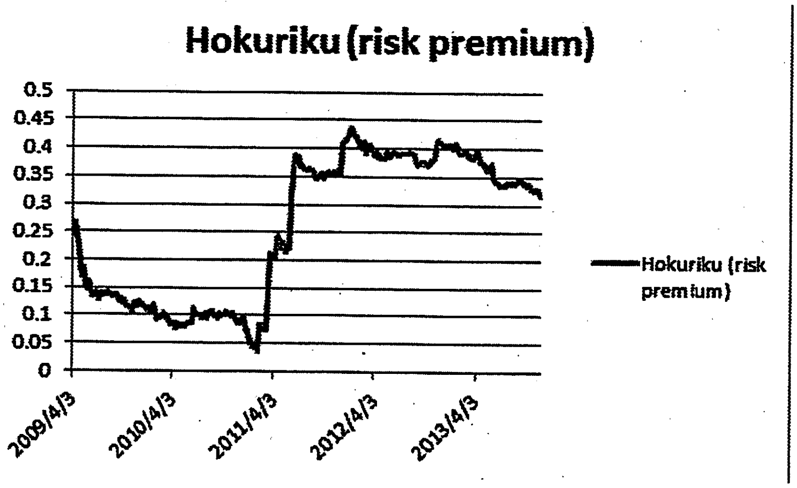

Figure 6: Bond risk premia and yield of Tohoku Electric Power

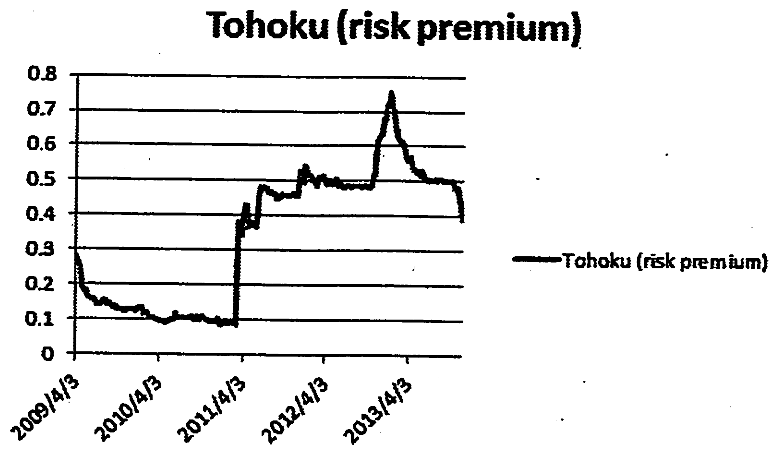

Figure 7: Bond risk premium of Shikoku Electric Power

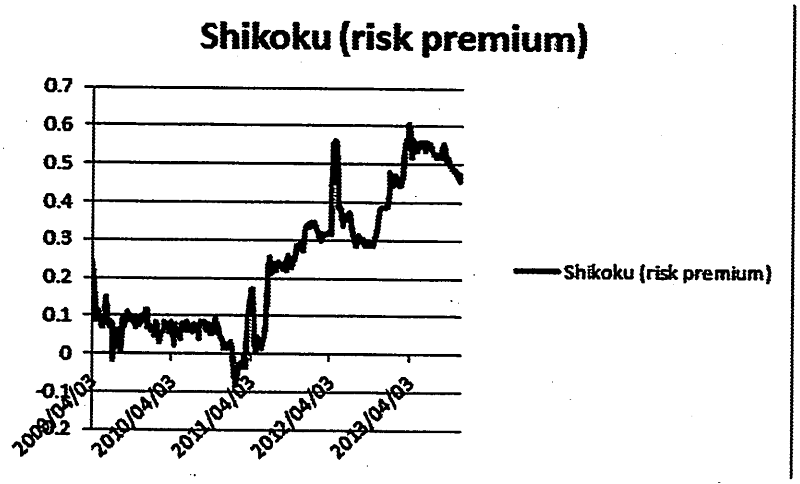

Figure 8: Bond risk premium of Kyushu Electric Power

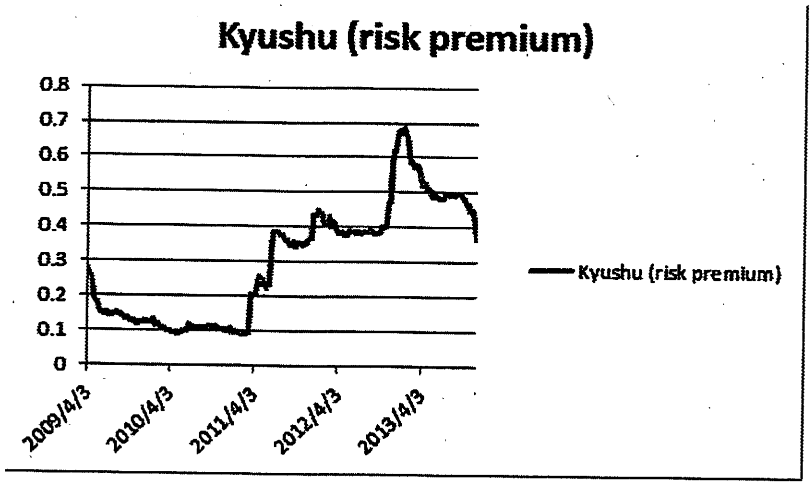

Figure 9: Bond risk premium of Hokkaido Electric Power

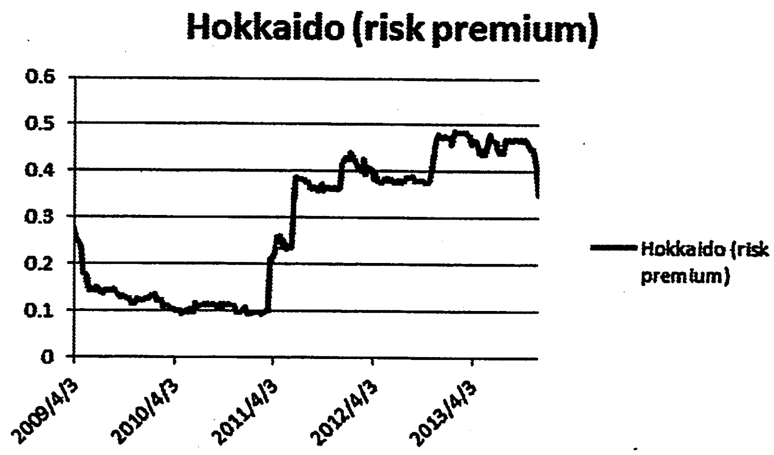

Figure 10: Bond risk premium of Okinawa Electric Power

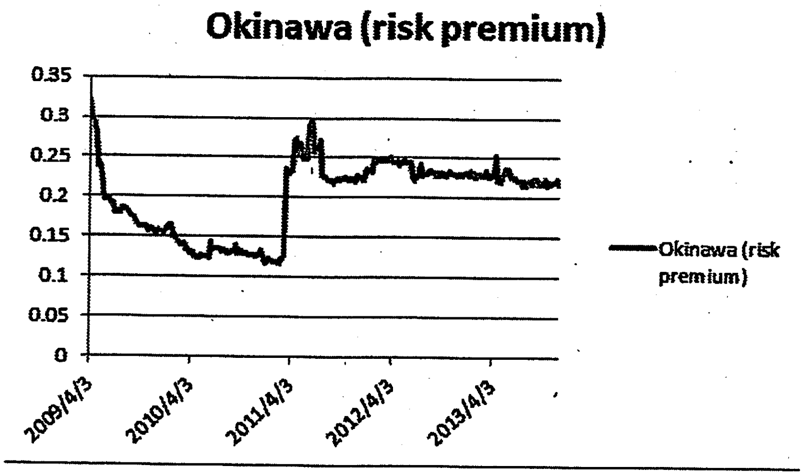

Figure 11: Term

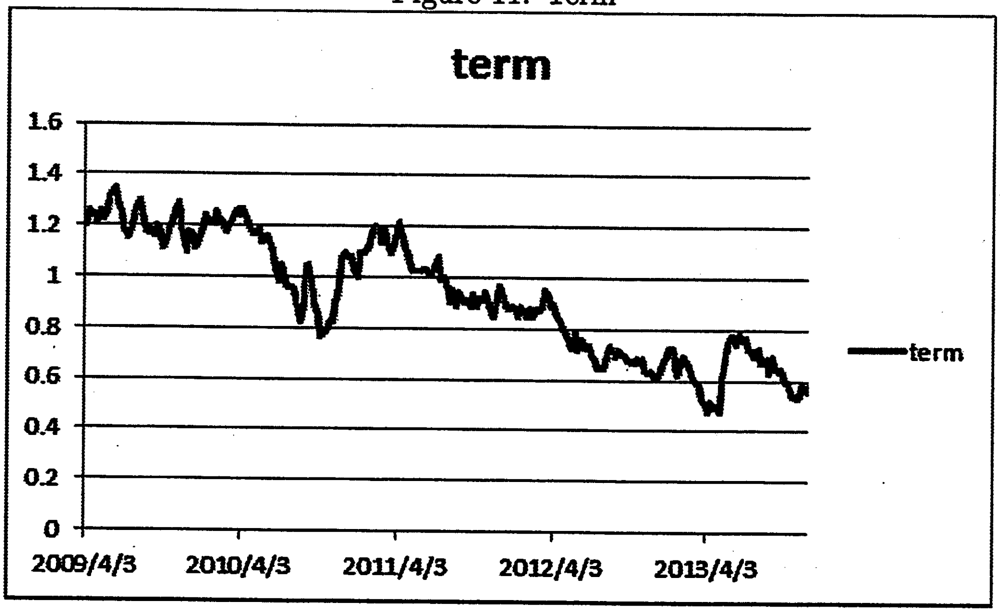

Figure 12: Topix Index Price

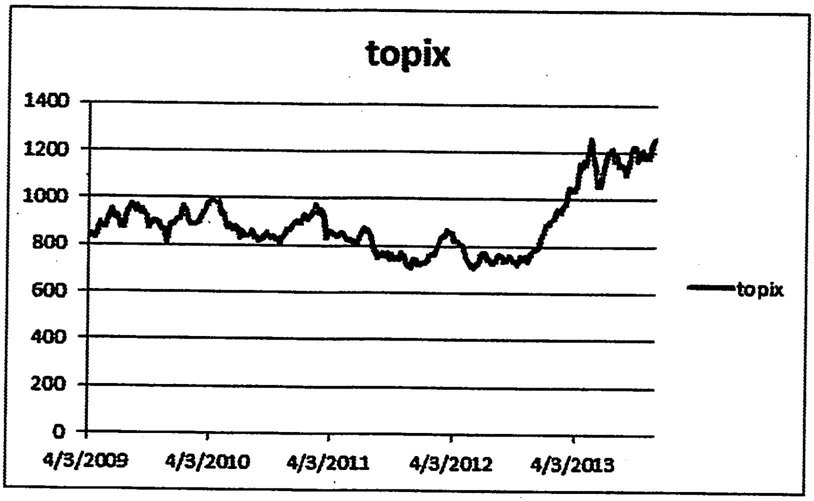

Figure 13: Risk Premium of TEPCO versus Non-TEPCO

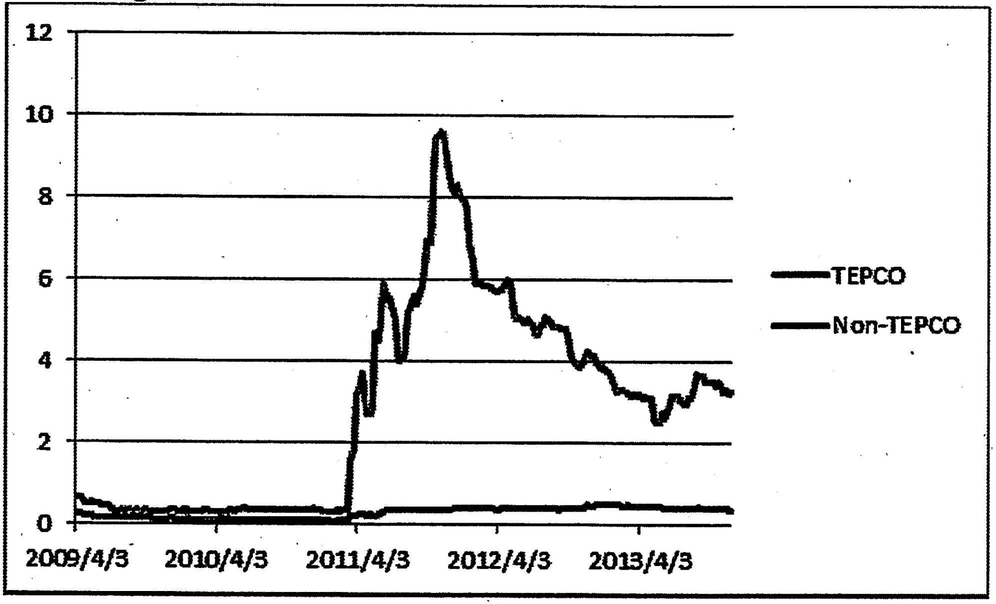

Figure 14: Risk Premium of Victim (with TEPCO) versus Non-Victim

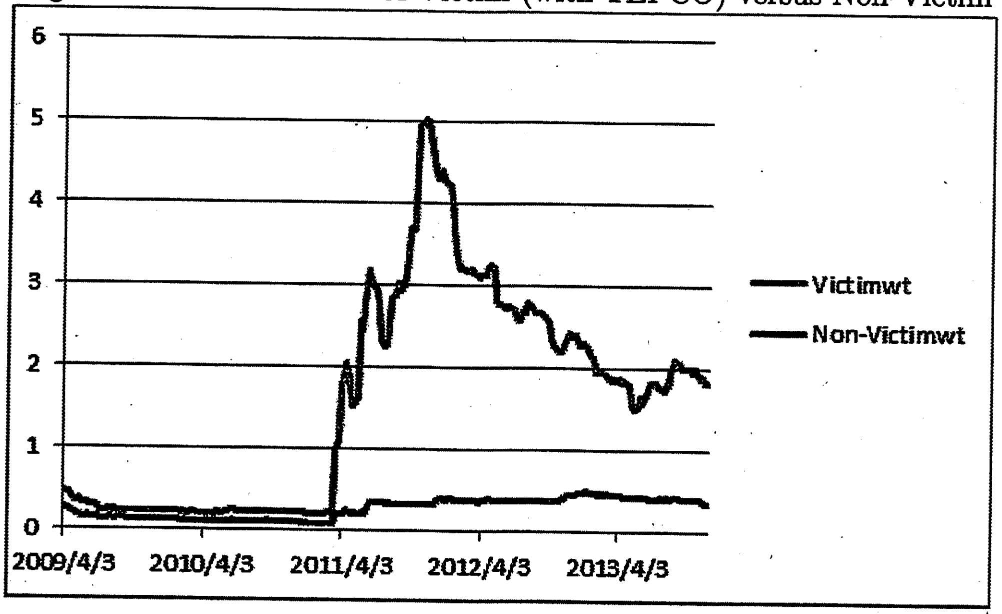

Figure 15: Risk Premium of Victim versus Non-Victim (without TEPCO)

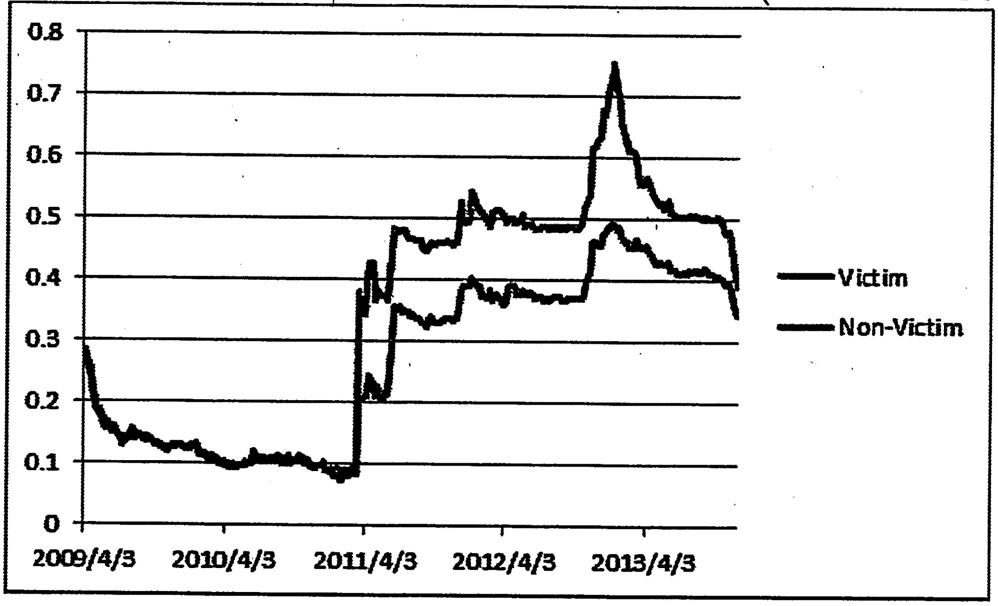

Figure 16: Risk Premium of Electric Power Companies with and without Nuclear Power Plants (with TEPCO)

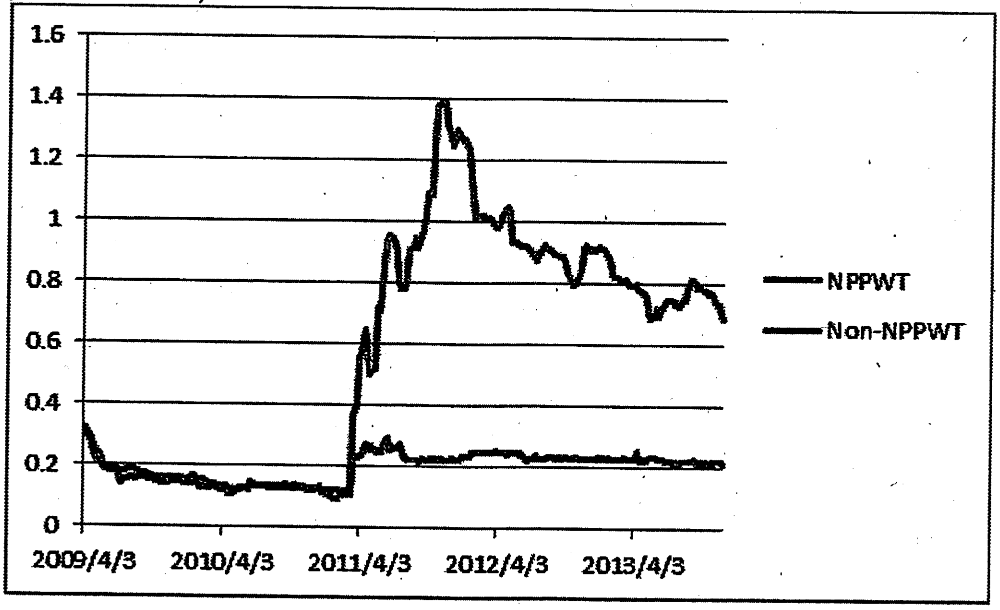

Figure 17: Risk Premium of Electric Power Companies with and without Nuclear Power Plants (without TEPCO)

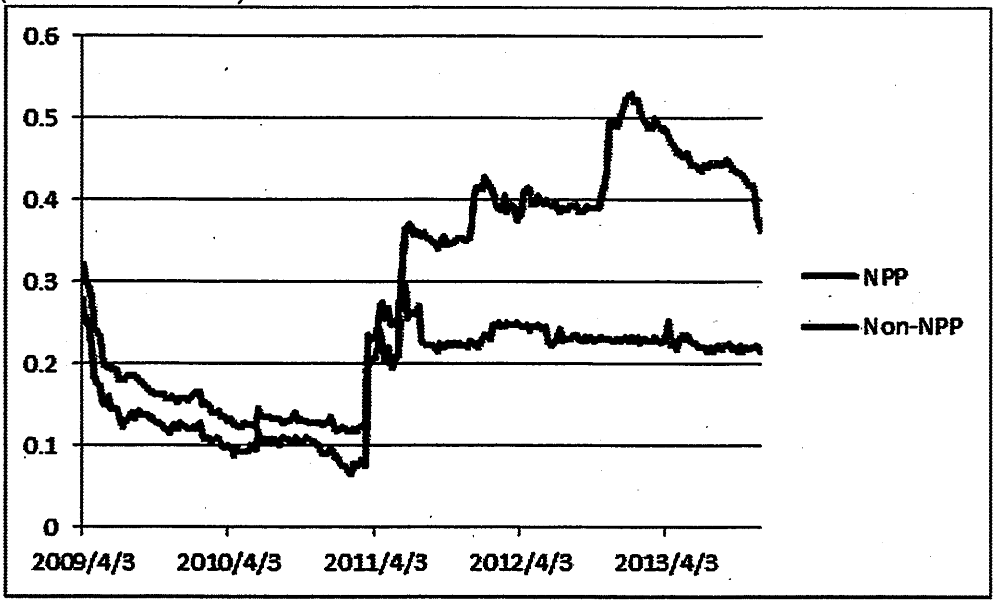

Figure 18: Risk Premium of Electric Power Companies with Large and Small Nuclear Power

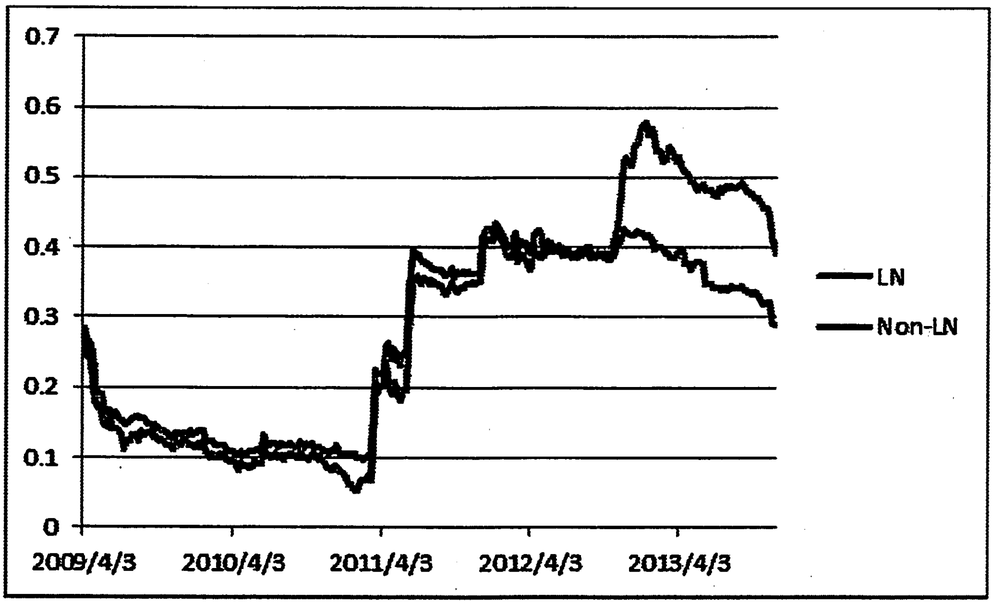

Figure 19: Risk Premium of Electric Power Companies with Old and Non-Old Nuclear Power Plants

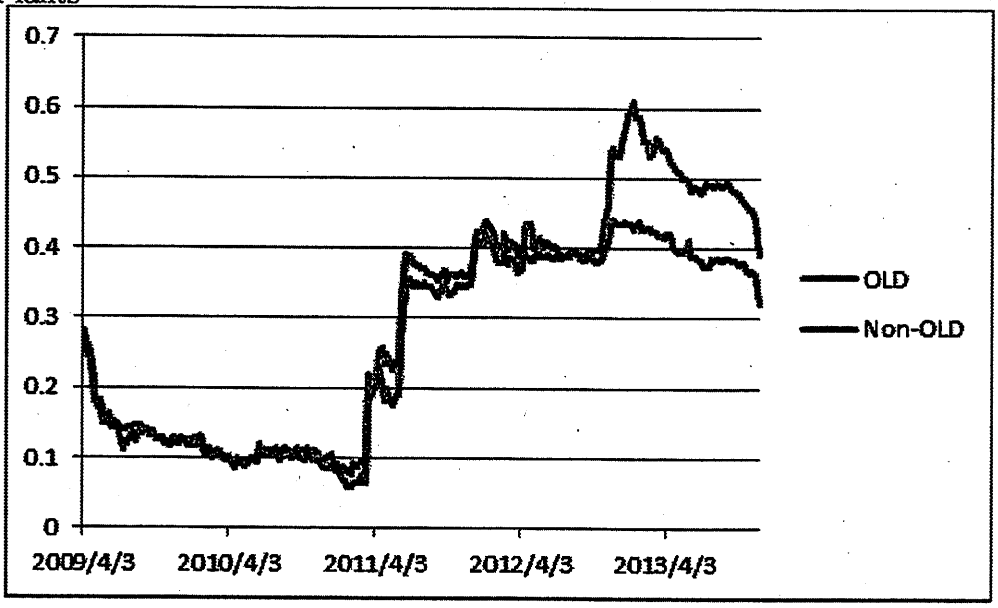

Figure 20: Risk Premium of Electric Power Companies with Mark 1 and Non-Mark 1 Type Nuclear Power Plants

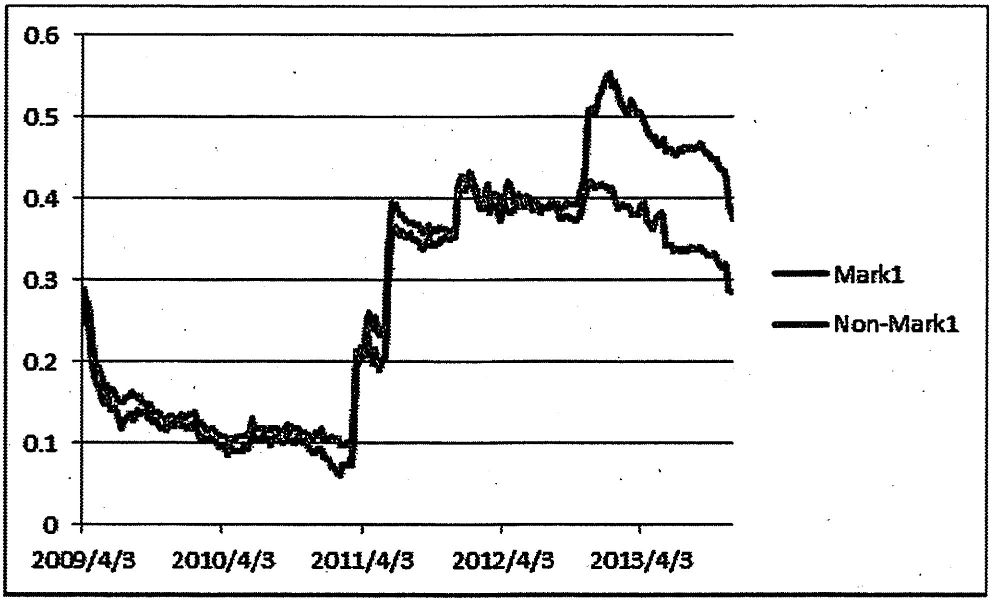

Table 1: Summary statistics for TEPCO

	bond risk premium	
	before 3.11	after 3.11
mean	0.360	4.673
median	0.196	4.112
max	1.623	16.718
min	0.082	0.616
s.d.	0.326	2.226
skewness	1.639	2.096
kurtosis	4.867	9.177

Table 2: Summary statistics for Chubu

	bond risk premium	
	before 3.11	after 3.11
mean	0.132	0.372
median	0.119	0.368
max	0.372	0.611
min	0.021	0.142
s.d.	0.057	0.069
skewness	0.830	0.081
kurtosis	3.497	4.141

Table 3: Summary statistics for Kansai

	bond risk premium	
	before 3.11	after 3.11
mean	0.139	0.503
median	0.129	0.478
max	0.376	1.016
min	0.050	0.164
s.d.	0.051	0.152
skewness	1.358	0.429
kurtosis	5.504	3.147

Table 4: Summary statistics for Chugoku

	bond risk premium	
	before 3.11	after 3.11
mean	0.133	0.365
median	0.134	0.366
max	0.357	0.498
min	0.025	0.137
s.d.	0.054	0.060
skewness	0.619	-0.722
kurtosis	4.020	4.265

Table 5: Summary statistics for Hokuriku

	bond risk premium	
	before 3.11	after 3.11
mean	0.112	0.362
median	0.103	0.362
max	0.324	0.516
min	-0.081	0.150
s.d.	0.051	0.060
skewness	0.847	-0.802
kurtosis	5.182	4.531

Table 6: Summary statistics for Tohoku

	bond risk premium	
	before 3.11	after 3.11
mean	0.123	0.504
median	0.117	0.492
max	0.358	0.888
min	0.007	0.283
s.d.	0.055	0.081
skewness	0.886	1.149
kurtosis	4.268	6.084

Table 7: Summary statistics for Shikoku

	bond risk premium	
	before 3.11	after 3.11
mean	0.063	0.361
median	0.071	0.341
max	0.243	0.605
min	-0.084	0.011
s.d.	0.047	0.143
skewness	-0.149	-0.348
kurtosis	5.594	2.559

Table 8: Summary statistics for Kyushu

	bond risk premium	
	before 3.11	after 3.11
mean	0.124	0.430
median	0.107	0.419
max	0.344	1.019
min	0.021	0.133
s.d.	0.057	0.120
skewness	0.911	0.904
kurtosis	3.401	5.605

Table 9: Summary statistics for Hokkaido

	bond risk premium	
	before 3.11	after 3.11
mean	0.123	0.402
median	0.105	0.405
max	0.333	0.594
min	0.021	0.151
s.d.	0.057	0.080
skewness	0.738	-0.449
kurtosis	3.130	3.787

Table 10: Summary statistics for Okinawa

	bond risk premium	
	before 3.11	after 3.11
mean	0.155	0.233
median	0.143	0.216
max	0.350	0.357
min	0.067	0.193
s.d.	0.057	0.037
skewness	0.649	1.206
kurtosis	2.883	3.697

Table 11: Summary statistics for Term

	term	
	before 3.11	after 3.11
mean	1.130	0.781
median	1.170	0.738
max	1.346	1.215
min	0.768	0.475
s.d.	0.134	0.168
skewness	-1.029	0.378
kurtosis	3.317	2.394

Table 12: Estimation Results for the equation (1) ~ (3)

	model (1) ($\bar{R}^2 = 0.836$)		model (2) ($\bar{R}^2 = 0.837$)		model (3) ($\bar{R}^2 = 0.958$)	
parameter	LSDV	t-value	LSDV	t-value	LSDV	t-value
α_1	0.527	1.713	0.528	1.718		
α_2	0.121	0.950	0.122	0.962	-0.039	-1.190
α_3	0.175	1.715	0.176	1.729	0.046	1.489
α_4	0.112	0.907	0.114	0.920	-0.045	-1.364
α_5	0.094	0.811	0.095	0.824	-0.053	-1.653
α_6	0.116	1.035	0.117	1.049	-0.025	-0.944
α_7	0.287	0.799	0.288	0.804	-0.200	-3.836
α_8	0.139	1.209	0.141	1.222	-0.007	-0.205
α_9	0.127	1.081	0.129	1.094	-0.019	-0.574
α_{10}	0.174	1.192	0.175	1.203	-0.129	-3.718
λ_1	0.276	1.877	0.462	6.638	0.646	9.742
λ_2			-0.289	-4.252	-0.248	-4.982
β_1	0.102	4.837	0.100	4.790	0.101	4.887
β_2	-0.208	-1.113	-0.403	-4.578	-0.431	-6.489
β_3			0.292	2.818	0.355	4.257
β_4			0.001	0.676	0.001	0.620
β_5			0.006	1.567	0.005	2.431
β_6			-0.004	-1.310	-0.004	-1.859
γ_1	4.039	35.935	4.039	35.802		
γ_2	0.108	6.227	0.108	6.231	0.114	6.426
γ_3	0.195	11.042	0.195	11.106		
δ_1	-0.000	-0.014	-0.000	-0.014	-0.014	-7.069
δ_2	-0.002	-0.861	-0.002	-0.861	0.001	5.061

Table 13: Estimation Results for the equation (4) ~ (5)

	model (4) ($\bar{R}^2 = 0.957$)		model (5) ($\bar{R}^2 = 0.961$)	
parameter	LSDV	t-value	LSDV	t-value
α_1				
α_2	-0.041	-1.170	-0.018	-0.637
α_3	0.044	1.372	0.015	0.495
α_4	-0.046	-1.339	-0.018	-0.680
α_5	-0.054	-1.618	-0.045	-1.704
α_6				
α_7	-0.203	-3.638	-0.231	-4.726
α_8	-0.008	-0.239	-0.038	-1.227
α_9	-0.020	-0.583	-0.010	-0.387
α_{10}	-0.017	-0.609		
λ_1	0.460	7.892	0.631	10.752
λ_2	-0.248	-5.034	-0.257	-5.141
β_1	0.099	4.775	0.097	4.696
β_2	-0.435	-5.919	-0.447	-5.940
β_3	0.353	4.119	0.367	4.165
β_4	0.001	0.621	0.001	0.616
β_5	0.005	2.300	0.005	2.329
β_6	-0.004	-1.895	-0.004	-1.899
γ_3	0.195	10.970		
γ_4			0.023	2.267
γ_5			0.067	2.938
γ_6			-0.075	-3.301
δ_1	-0.014	-5.963	-0.015	-6.335
δ_2	0.001	4.772	0.001	4.798