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Solar Power Generation and Risk Transfer Systems

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ABSTRACT

This study analyzes the uncertainty in the amount of electricity supply in solar power generation because actual sunshine duration is unknown in advance. In particular, the study considers how risk transfer systems such as insurance and derivatives affect the prevalence of solar power generation. Furthermore, we investigate how the electricity price in the feed-in tariff (FIT) scheme introduced in Japan in July 2012 relates to the prevalence of solar power generation.

If additional revenue is larger than additional cost due to the application of a risk transfer system, we derive the following results from our economic model analysis. First, an increase in electricity price in the FIT scheme and in the expected amount of electricity supply and a decrease in the cost of solar panels increases the availability of a risk transfer system. Second, promoting the availability of a risk transfer system leads to increased solar power generation.

JEL Classifications: *G22, Q21, Q28*

Keywords: *solar power generation; risk transfer; feed-in tariff (FIT); economic model*

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I. INTRODUCTION

After the Great East Japan Earthquake in March 2011, energy policy in Japan was changed drastically because of concerns about the safety of nuclear power plants. Subsequently, after September 2013, as of June 2015, all nuclear power plants in Japan were shut down. This situation has increased the attention towards renewable energy such as solar power, wind power, and geothermal power as sources of electric power. This is because electric power generation through renewable energy sources emits neither carbon dioxide nor radioactivity. However, according to the summary of press conference comments by chairman of the Federation of Electric Power Companies of Japan (May 23, 2014), the share of electric power generation in renewable energy except for hydroelectric power was only 2.2 percent in fiscal 2013.[1]

In order to increase this share, the Japanese government started the feed-in tariff (FIT) scheme for renewable energy in July 2012. Under this scheme, Japanese electric power companies have to purchase electricity produced by renewable energy at a price predetermined by the government. According to the handout that used in the committee in the Agency for Natural Resources and Energy (p.53), solar power generation in Japan has constituted the major share (more than 97 percent) of the increase in power generation from renewable sources.[2] Thus, solar power is the main source of renewable energy in Japan.

There are many studies on solar power generation that focus on the FIT scheme in Japan. For example, Ayoub and Naka (2012) developed a simulation analysis for investigating the FIT scheme for renewable energies in Japan. Kosugi (2013) investigated financial support including the FIT scheme for increasing solar power generation in Japan. Since some of the issues related to solar power generation are not specific to Japan, several relevant studies examine them in many other countries. These include Rigter and Vidican (2010) (China), Topkaya (2012) (Turkey), Jacobs et al. (2013) (Latin America and Caribbean region), Tveten et al. (2013) (Germany), Martin and Rice (2013) (Australia), Tongsopit and Greacen (2013) (Thailand), and Moosavian et al. (2013), who discussed energy policies, including FIT schemes, in Australia, Canada, China, Japan, France, Germany, and U.S.A.

The FIT scheme can remove the uncertainty in electricity price, because the price of electricity is fixed in the scheme. However, the amount of electricity generated by solar power is still uncertain because the actual duration of sunshine is unknown in advance. Therefore, despite the FIT scheme addressing the issue of uncertainty in electricity price, the uncertainty related to the amount of electricity supply persists.

A possible method to cope with this uncertainty is to apply a risk transfer system such as insurance and derivatives. According to Yoneyama Seminar (2014), some Japanese non-life insurance firms provide compensation contracts for covering losses caused by poor sunshine duration. We believe that applying risk transfer systems change the purchasing behavior of firms with respect to solar panels and finally affect the prevalence of solar power generation.

The purpose of this study is to analyze the uncertainty in the amount of electricity supply generated by solar power generation. In particular, this study considers how a risk transfer system for alleviating that uncertainty affects the prevalence of solar power generation. Furthermore, we investigate how the electricity price in the FIT scheme, amount of electricity supply, and cost of solar panels relate to the prevalence of solar power generation.

II. THE MODEL

Consider a firm that wants to purchase solar panels. This firm also decides whether to apply a risk transfer system for alleviating the uncertainty in the amount of electricity supply. We assume that all solar panels are identical. This firm is assumed to be strictly risk averse to the uncertainty relating to electricity sales profit. The firm uses the following two-stage decision-making process.

In the first stage, this firm chooses to purchase the number of solar panels that is denoted by $x_i \geq 0$ where $i \in \{T, N\}$ and the subscripts T and N represent the situations in which the firm applies and does not apply the risk transfer system respectively. $c > 0$ is the unit cost of a solar panel. The amount of electricity supply from a solar panel is written as $e = \mu + \varepsilon$ where $\mu \equiv E[e]$, as we assume that the random error, ε, is normally distributed with a zero mean and a variance of $\sigma^2 > 0$ ($E[\bullet]$ represents the operator of expectation). Through the FIT scheme, the firm can sell its produced electricity to the electric company. We assume that all produced electricity can be sold at a unit price, $p > 0$, which is predetermined by the FIT scheme.

In the second stage, the firm decides whether to apply a risk transfer system after the firm purchases solar panels. The risk premium per solar panel is denoted by $\theta > 0$. Thus, when the firm applies a risk transfer system, the total amount of premium is θx_T. This risk transfer system compensates $(\mu - e)px_T$ if the actual amount of electricity supply is less than μ. In contrast, the risk transfer system does not compensate if the actual amount of electricity supply is more than μ.

The utility function of the firm, u_i, is specified as

$$u_i = -\exp(-r\Pi_i) \tag{1}$$

where Π_i and $r > 0$ represent the profit of firm and the degree of absolute risk aversion, respectively. Then, the certainty equivalent, which is denoted by CE_i, can be computed as

$$CE_i = E[\Pi_i] - \frac{r}{2} Var[\Pi_i] \tag{2}$$

where $Var[\bullet]$ represents the variance operator.

This firm has two options in the model. The firm can choose x_N^* and to not apply a risk transfer system. Alternatively, the firm can choose x_T^* and to apply a risk transfer system. The superscript "*" represents the optimal value. Thus, we solve the model by deriving x_N^* and x_T^*. We then compute CE_N^* and CE_T^*. Finally, we compare them to examine the decision to apply a risk transfer system.

First, consider the situation in which the firm does not apply a risk transfer system. In this situation, the profit of the firm is given by

$$\Pi_N = (pe - c)x_N = \{p(\mu + \varepsilon) - c\}x_N \tag{3}$$

Then, $E[\Pi_N]$ and $Var[\Pi_N]$ can be written as

$$E[\Pi_N] = (p\mu - c)x_N \tag{4}$$

$$Var[\Pi_N] = E\left[\{\Pi_N - E[\Pi_N]\}^2\right] = p^2 x_N^2 \sigma^2 \tag{5}$$

The certainty equivalent is

$$CE_N = (p\mu - c)x_N - \frac{r}{2}p^2 x_N^2 \sigma^2 \tag{6}$$

From the first order condition, the optimal number of solar panels can be written as[3]

$$\frac{\partial CE_N}{\partial x_N} = p\mu - rp^2 x_N^* \sigma^2 = 0 \Rightarrow x_N^* = \frac{p\mu - c}{rp^2\sigma^2} \tag{7}$$

In order to ensure $x_N^* > 0$, we assume that the condition $p\mu - c > 0$ is satisfied.[4]

Next, consider the situation in which the firm applies a risk transfer system. The profits of the firm are

$$\Pi_T = \{p(\mu + \varepsilon) - c - \theta\}x_T, \text{ if } \ e \geq \mu \tag{8}$$

$$\Pi_T = \{p\mu - c - \theta\}x_T, \text{ if } \ e \leq \mu \tag{9}$$

The symmetry of the normal distribution function implies that the probability that $e \geq \mu$ and the probability that $e \leq \mu$ are both equal to $1/2$. Thus, we can show

$$\begin{aligned} E[\Pi_T] &= \frac{1}{2}(p\bar{\mu} - c - \theta)x_T + \frac{1}{2}(p\mu - c - \theta)x_T \\ &= \frac{1}{2}x_T\{p(\bar{\mu} + \mu) - 2(c + \theta)\} \end{aligned} \tag{10}$$

where

$$\bar{\mu} \equiv \int_{\mu}^{\infty} e f\left(e \mid e \geq \mu\right) de = \mu + \sqrt{\frac{2\sigma^2}{\pi}} \tag{11}$$

and $\bar{\mu} \geq \mu$. Furthermore, $f\left(e \mid e \geq \mu\right)$ represents the normal distribution function conditional on $e \geq \mu$. The expected amount of compensation, which is equal to the actuarially fair premium, can be computed as

$$\int_{-\infty}^{\mu} (\mu - e) f(e) de = \sqrt{\frac{\sigma^2}{2\pi}} \tag{12}$$

where $f(e)$ represents the normal distribution function. Using equation (12), we can write

$$\theta = (1+\lambda)\sqrt{\frac{\sigma^2}{2\pi}} \tag{13}$$

where $\lambda \geq 0$ represents the loading rate of the premium. Substituting equations (11) and (13) in equation (10), we have

$$\begin{aligned} E[\Pi_T] &= x_T \left\{ p\left(\mu + \sqrt{\frac{\sigma^2}{2\pi}} \right) - c - (1+\lambda)\sqrt{\frac{\sigma^2}{2\pi}} \right\} \\ &= x_T \left\{ p\mu - c + \sqrt{\frac{\sigma^2}{2\pi}} (p - 1 - \lambda) \right\} \end{aligned} \tag{14}$$

Now, $Var[\Pi_T]$ can be written as

$$Var[\Pi_T] = E\left[\{\Pi_T - E[\Pi_T]\}^2 \right] = \frac{p^2 x_T^2 \sigma^2}{2} \tag{15}$$

Thus, the certainty equivalent is

$$CE_T = x_T \left\{ p\mu - c + \sqrt{\frac{\sigma^2}{2\pi}} (p - 1 - \lambda) \right\} - \frac{r}{4} p^2 x_T^2 \sigma^2 \tag{16}$$

Consequently, the optimal number of solar panels can be written as[5]

$$\frac{\partial CE_T}{\partial x_T} = p\mu - c + \sqrt{\frac{\sigma^2}{2\pi}}(p-1-\lambda) - \frac{r}{2}p^2 x_T^* \sigma^2 = 0$$
$$\Rightarrow x_T^* = \frac{2\left\{p\mu - c + \sqrt{\frac{\sigma^2}{2\pi}}(p-1-\lambda)\right\}}{rp^2\sigma^2} \tag{17}$$

In order to guarantee $x_T^* > 0$, we assume the following equation is satisfied.[6]

$$p\mu - c + \sqrt{\frac{\sigma^2}{2\pi}}(p-1-\lambda) > 0 \tag{18}$$

Using equations (7) and (17), the following relationship is derived.

$$x_T^* \geq x_N^* \Leftrightarrow p\mu - c + \sqrt{\frac{\sigma^2}{2\pi}}(p-1-\lambda) \geq 0 \tag{19}$$

From equation (19), we know that $x_T^* \geq x_N^*$ if $p \geq 1+\lambda$. The condition $p \geq 1+\lambda$ implies that the electricity price in the FIT scheme is relatively high and/or the loading rate is relatively low. In order to know the implication of $p \geq 1+\lambda$ in detail, multiplying both side of $p \geq 1+\lambda$ by $\sqrt{\sigma^2/2\pi}$, we obtain

$$\sqrt{\frac{\sigma^2}{2\pi}}p \geq (1+\lambda)\sqrt{\frac{\sigma^2}{2\pi}} \tag{20}$$

The left-hand side of equation (20) represents the additional expected revenue due to application of a risk transfer system because

$$\sqrt{\frac{\sigma^2}{2\pi}}p = \frac{1}{2}p(\mu + \bar{\mu}) - p\mu \tag{21}$$

By contrast, the right-hand side of equation (20) represents the amount of premium paid for the application of a risk transfer system. Thus, we find that $p \geq 1+\lambda$ indicates that additional revenue is larger than additional cost due to the application of a risk transfer system. However, $p \geq 1+\lambda$ is a sufficient condition for realizing $x_T^* \geq x_N^*$. In other words, it is possible to realize $x_T^* \geq x_N^*$ even if $p < 1+\lambda$. From equations (5) and (15), we find

$$\mathrm{Var}[\Pi_T] = \frac{\mathrm{Var}[\Pi_N]}{2} \tag{22}$$

when the number of solar panels is the same. Thus, the firm might choose to apply a risk transfer system even if $p < 1 + \lambda$ because it alleviates the uncertainty in the amount of electricity supply.

III. COMPARISON

Substituting equations (7) and (17) in equations (6) and (16), the optimal certainty equivalent in each situation is computed as follows:

$$CE_N^* = \frac{(p\mu - c)^2}{2rp^2\sigma^2} \tag{23}$$

$$CE_T^* = \frac{\left\{\sqrt{2\pi}(p\mu - c) + \sqrt{\sigma^2}(p - 1 - \lambda)\right\}^2}{2\pi r p^2 \sigma^2} \tag{24}$$

In order to check which certainty equivalent is larger, we define $\Delta \equiv CE_T^* - CE_N^*$. Thus the firm applies (does not apply) a risk transfer system if $\Delta \geq 0$ ($\Delta < 0$). From equations (23) and (24), we have

$$\Delta = \frac{\left\{\sqrt{2\pi}(p\mu - c) + \sqrt{\sigma^2}(p - 1 - \lambda)\right\}^2 - \pi(p\mu - c)^2}{2\pi r p^2 \sigma^2} \tag{25}$$

We find that the sign of equation (25) is indeterminate; therefore, it is ambiguous whether the firm will apply a risk transfer system. Since, the denominator in equation (25) is always positive, we know $\mathrm{Sign}[\Delta] = \mathrm{Sign}[\Omega]$ where $\mathrm{Sign}[\bullet]$ is the sign operator and Ω denotes the numerator in equation (25), that is,

$$\Omega \equiv \left\{\sqrt{2\pi}(p\mu - c) + \sqrt{\sigma^2}(p - 1 - \lambda)\right\}^2 - \pi(p\mu - c)^2 \tag{26}$$

Equation (26) consists of five exogenous variables, p, c, μ, σ^2, and λ. It implies that the exogenous variable r does not affect the sign of Ω. Therefore, the magnitude of r does not determine whether the firm will apply a risk transfer system.

Comparative statics for five exogenous variables are conducted as follows:

$$\frac{\partial\Omega}{\partial p} = 2\left\{\sqrt{2\pi}\left(\sqrt{\frac{\pi}{2}}\mu + \sqrt{\sigma^2}\right)(p\mu - c) + \sqrt{\sigma^2}\left(\sqrt{\sigma^2} + \sqrt{2\pi}\mu\right)(p - 1 - \lambda)\right\} \tag{27}$$

$$\frac{\partial\Omega}{\partial c} = -2\sqrt{2\pi}\left\{\frac{\sqrt{2\pi}}{2}(p\mu - c) + \sqrt{\sigma^2}(p - 1 - \lambda)\right\} \tag{28}$$

$$\frac{\partial\Omega}{\partial \mu} = 2\sqrt{2\pi}p\left\{\frac{\sqrt{2\pi}}{2}(p\mu - c) + \sqrt{\sigma^2}(p - 1 - \lambda)\right\} \tag{29}$$

$$\frac{\partial\Omega}{\partial \sigma^2} = 2(p - 1 - \lambda)\left\{\sqrt{2\pi}(p\mu - c) + \sqrt{\sigma^2}(p - 1 - \lambda)\right\} \tag{30}$$

$$\frac{\partial\Omega}{\partial \lambda} = -2\sqrt{\sigma^2}\left\{\sqrt{2\pi}(p\mu - c) + \sqrt{\sigma^2}(p - 1 - \lambda)\right\} < 0 \tag{31}$$

The implications of equations (27) through (31) are as follows. First, from equation (31), we find that an increase in the loading rate always lowers the availability of the risk transfer system. Second, the signs of equations (27) to (30) are indeterminate. However, from equations (27) to (29), we know that $p \geq 1 + \lambda$ is sufficient condition for realizing $\partial\Omega/\partial p > 0$, $\partial\Omega/\partial c < 0$, and $\partial\Omega/\partial\mu > 0$. As mentioned before, the condition $p \geq 1 + \lambda$ represents the relatively higher electricity price in the FIT scheme and/or relatively lower loading rate. From the comparative statics results, if $p \geq 1 + \lambda$ is satisfied, an increase in electricity price in the FIT scheme and in the expected amount of electricity supply and a decrease in the cost of solar panels leads to increased availability of the risk transfer system.

Additionally, we know that $p \geq 1 + \lambda$ is also the condition for realizing $x_T^* \geq x_N^*$. Thus, in this situation, we find that promoting the availability of a risk transfer system by controlling the electricity price in the FIT scheme, expected amount of electricity supply, and cost of solar panels leads to increased solar power generation.

IV. CONCLUDING REMARKS

This study analyzed the uncertainty in the amount of electricity supply generated by solar power. In particular, this study considered how risk transfer systems for alleviating that uncertainty, such as insurance and derivatives, affect the prevalence of solar power generation. Furthermore, we investigated how the electricity price in the FIT scheme is related to the prevalence of solar power generation.

From our economic model analysis, if additional revenue is larger than additional cost due to the application of a risk transfer system, we can derive the following results. First, an increase in electricity price in the FIT scheme and in the expected amount of electricity supply and a decrease in the cost of solar panels leads to increased availability of risk transfer systems. Second, promoting the availability of risk transfer systems by controlling the electricity price in the FIT scheme, expected amount of electricity supply, and cost of solar panels leads to increase in solar power generation.

These results can help explain how to expand the availability of risk transfer systems. Additionally, they can contribute to consider how to increase solar power generation. We see that setting higher electricity prices in the FIT scheme has a tendency to enhance the availability of risk transfer systems, which in turn promotes solar power generation. Furthermore, we know that a competitive market in risk transfer systems has a tendency to increase the availability of risk transfer systems and the prevalence of solar power generation because of the resultant decrease in the loading rate. Thus, for example, we can prospect there is the relationship between the degree of competition in insurance market and prevalence of solar power generation. Furthermore, R&D investments for raising the amount of electricity supply and lowering the cost of solar panels are linked to an increase in the availability of risk transfer systems and in the prevalence of solar power generation.

There are several possibilities to extend the model in this study. For example, in our model, the levels of premium and compensation in the risk transfer system were exogenous variables. However, suppliers in risk transfer systems such as insurance companies can decide the levels of premium and compensation for maximizing own profits. Another example, this study did not consider the optimal amount of electricity supply in solar power generation which is decided by generation costs. Actually, the amount of electricity supply in solar power generation might be greater than the optimal amount when electricity price in FIT scheme is too high. In this regard, we believe how to determine electricity price in FIT scheme for realizing the optimal amount of electricity supply in solar power generation is valuable to analyze in the model. These points remain an open question for which additional work is required.

ENDNOTES

1. Source: the following website (accessed on June 19, 2015). http://www.fepc.or.jp/english/news/conference/__icsFiles/afieldfile/2014/05/28/kaiken_e_20140528.pdf
2. Source: the following website (accessed on June 19, 2015) (in Japanese). http://www.enecho.meti.go.jp/committee/council/basic_policy_subcommittee/016/pdf/016_008.pdf
3. The second-order condition is always satisfied because $\partial^2 CE_N / \partial x_N^2 = -rp^2\sigma^2 < 0$.
4. If this assumption is not satisfied, the optimal number of solar panels becomes zero.
5. The second-order condition is always satisfied because $\partial^2 CE_T / \partial x_T^2 = -rp^2\sigma^2 / 2 < 0$.
6. If this assumption is not satisfied, the optimal number of solar panels becomes zero.

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