Measuring Risk Aversion for Nuclear Power Plant Accident: Results of Contingent Valuation Survey in Korea

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1. Introduction

Within the evaluation of the external cost of nuclear energy, the estimation of the external cost of nuclear power plant (NPP) severe accident is one of the major topics to be addressed. For the evaluation of the external cost of NPP severe accident, the effect of public risk averse behavior against the group accidents, such as NPP accident, dam failure, must be addressed [1, 2]. Although the equivalent fatalities from a single group accident are not common and its risk is very small compared to other accidents, people perceive the group accident more seriously. In other words, people are more concerned about low probability/high consequence events than about high probability/low consequence events having the same mean damage.

One of the representative method to integrate the risk aversion in the external costs of severe nuclear reactor accidents was developed by Eeckoudt et al. [3], and he used the risk aversion coefficient, mainly based on the analysis of financial risks in the stock markets to evaluate the external cost of nuclear severe accident. However, the use of financial risk aversion coefficient to nuclear severe accidents is not appropriate, because financial risk and nuclear severe accident risk are entirely different [4].

In this paper, the individual-level survey was conducted to measure the risk aversion coefficient and estimate the multiplication factor to integrate the risk aversion in the external costs of NPP severe accident.

2. Methods and Results

In this paper, the individual survey questionnaires were appropriately designed and the relative risk aversion coefficient, as a measure of public risk aversion to NPP accident, was estimated based on a structural estimation method, while allowing both heterogeneity in risk aversion across demographic groups and the potential noise in survey responses.

2.1 Design of Individual Survey Questionnaires

There have been several attempts of using a simple experimental survey using a multiple price list (MPL) design, where each subject is presented with two choices, consisting of risk-safe choice and risky choice, to estimate the risk aversion in financial markets using hypothetical lottery-choice decision questionnaires with payoff matrix [5, 6].

However, the lottery faced by an individual is generally described as low-probability/high-consequence situation in the case of group accidents, such as NPP accident, compared to the case of general situation in economic market, where the potential amount of gain or loss of lottery faced by an individual is far less. Therefore, the lottery-choice decision questions for estimating risk aversion for NPP accident must be designed considering the following factors: 1) An individual is faced with the situation where he loses certain amount of wealth and 2) The situation is characterized by very small probability of great loss of wealth with very high probability of no loss.

Table 1 shows the individual survey questionnaires used in this study. Notice that the certain individual loss for risk-safe choice (Option A) with relatively low loss of wealth choice and a very low probability for a high loss of wealth for risky choice (Option B).

The logic behind this survey questionnaires is that the expected value of Option A is higher than that of Option B in the first decision problem, thus, only an extreme risk seeker would choose Option B, on the contrary to the case of last decision problem, where extremely risk averse individual choose Option A.

Individual survey was conducted by a professional online research company with a sample size of 1000 participants where each participant was informed on a specific situation and was asked to choose Option A or B in each problem. Embedded within the survey were general demographic items (i.e. age, gender and residency) and public perception on the NPP accident.

Table I: Ten Paired Hypothetical Lottery-Choice Decisions

Problem	Type of choice	
	Option A	Option B
1	A sure loss of 0.1 million Won	A possibility of 5/100 to lose 0.1 billion Won
2	A sure loss of 0.1 million Won	A possibility of 2/100 to lose 0.1 billion Won
3	A sure loss of 0.1 million Won	A possibility of 1/100 to lose 0.1 billion Won
4	A sure loss of 0.1 million Won	A possibility of 5/1000 to lose 0.1 billion Won
5	A sure loss of 0.1 million Won	A possibility of 2/1000 to lose 0.1 billion Won
6	A sure loss of 0.1 million Won	A possibility of 1/1000 to lose 0.1 billion Won

7	A sure loss of 0.1 million Won	A possibility of 5/10000 to lose 0.1 billion Won
8	A sure loss of 0.1 million Won	A possibility of 2/10000 to lose 0.1 billion Won
9	A sure loss of 0.1 million Won	A possibility of 1/10000 to lose 0.1 billion Won
10	A sure loss of 0.1 million Won	A possibility of 0 to lose 0.1 billion Won

2.2 Structural Estimation of Risk Aversion Coefficient

It is assumed that the risk-safe choices over risky alternatives follow the expected utility theory. To estimate the risk aversion coefficient for NPP accident, the following functional form of the CRRA utility function is defined:

$$U(W) = \frac{W^{1-\sigma}}{1-\sigma} \quad (1)$$

Note that the expected utility is used from hypothetical loss of wealth for both option, distinguished from expected utility from wealth.

Following previous studies [5, 6], the probability of choosing risk-safe choice (Option A) are specified as the associated expected utility divided by the sum of the expected utilities for the two options:

$$\nabla EU = EU_A^{\frac{1}{\mu}} / (EU_A^{\frac{1}{\mu}} + EU_B^{\frac{1}{\mu}}) \quad (2)$$

Note that the index is in the form of a cumulative probability distribution function defined over the ratio between the expected utility of the two choices which is dependent on the risk aversion coefficient. Also, a noise parameter is introduced to capture the insensitivity of choice probabilities to loss options via the probabilistic choice rule.

By ignoring the responses that reflect indifference choices between risk-safe choice and risky choice, the conditional log-likelihood function is constructed:

$$\ln L(\sigma, \mu; y, S) = \sum_{i=1}^{N}\sum_{j=1}^{10}[(\ln(\nabla EU)|y_i^j = 1) + (\ln(1-\nabla EU)|y_i^j = -1)] \quad (3)$$

where y =1 (or -1) denotes individual's selection of Option A (or B) for each lottery question. S is a vector of demographic characteristics of individuals including gender, age, education level, annual household income and individual's perception on NPP accident. The heterogeneity in risk aversion coefficient were allowed where it is specified as linear functions of individual characteristics, S.

Using the survey respondents' choice for ten paired hypothetical lottery-choice decision questionnaires, the risk aversion coefficient is estimated based on the maximum likelihood estimation (MLE) method.

2.3 Estimation of multiplication factor

To illustrate the evaluation of the multiplication factor, a risk situation characterized by N states of the world with probabilities ($p_1, p_2, \cdots, p_i, \cdots, p_N$) and associated fractions of loss of wealth ($X_1, X_2, \cdots, X_i, \cdots, X_N$). Based on the utility theory, the utility function of a risk-averse individual can be characterized by a CRRA utility function, thus, the perceived loss, or the maximum wealth that the risk averse individual would be willing to loose in exchange for avoiding the lottery, is given by:

$$PL_{RA} = W_0 - U_{RA}^{-1}(E(U^*)) = W_0\{1 - [\sum_{i=1}^{N} p_i(1-X_i)^{1-\sigma}]^{\frac{1}{1-\sigma}}\} \quad (4)$$

$$E(U^*) = \sum_{i=1}^{N} p_i U_{RN}(W_0(1-X_i)) \quad (5)$$

If instead, the individual were risk-neutral, where the utility function of a risk-neutral individual can be characterized by a linear function, the maximum wealth he would be willing to loose is given by:

$$PL_{RN} = W_0(1 - \sum_{i=1}^{N} p_i(1-X_i)) \quad (6)$$

While the external cost of NPP accident is calculated assuming risk neutrality in expected value approach, in order to take account of risk aversion, the external cost must multiplied by the multiplication factor, defined as:

$$M = \frac{PL_{RA}}{PL_{RN}} = \frac{1 - [\sum_{i=1}^{N} p_i(1-X_i)^{1-\sigma}]^{\frac{1}{1-\sigma}}}{1 - \sum_{i=1}^{N} p_i(1-X_i)} \quad (7)$$

Note that in order to estimate the multiplication factor in case of the NPP accident, various states of the world must be determined considering the following factors: 1) the number of affected population to NPP accident depending on the area near NPP, 2) the states of lotteries for an individual and 3) the economic effects associated with NPP accident.

3. Conclusions

This study propose an integrated framework on estimation of the external cost associated with severe accidents of NPP considering public risk aversion behavior. The theoretical framework to estimate the risk aversion coefficient/multiplication factor and to assess economic damages from a hypothetical NPP accident was constructed.

Based on the theoretical framework, the risk aversion coefficient can be analyzed by conducting public survey with a carefully designed lottery questions. Compared to the previous studies on estimation of the external cost of NPP accident, the proposed framework can analytically quantify the risk aversion coefficient, as well as, estimate the accident risk response cost.

This study is expected to give insight on external cost estimation of both NPP and other severe accident cases of various energy sectors, especially in terms of accident risk response cost.

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REFERENCES

[1] O'Riordan, Timothy, and James Cameron, eds. Interpreting the precautionary principle. Vol. 2. Earthscan, 1994.
[2] Kirkwood, Ralph, and Anite Longley, eds. Clean technology and the environment. Springer, 1994.
[3] Eeckhoudt, L., C. Schieber, and T. Schneider. "Risk aversion and the external cost of a nuclear accident." Journal of environmental Management 58.2 (2000): 109-117.
[4] Lee, Yong Suk, and Byung Chul Lee. "The External Cost Evaluation of the Nuclear Severe Accident Using CVM.",, Transactions of the Korean Nuclear Society Autumn Meeting, Gyeongju, Korea, Nov. 2006.
[5] Holt, Charles A., and Susan K. Laury. "Risk aversion and incentive effects." American economic review 92.5 (2002): 1644-1655.
[6] Andersen, Steffen, et al. "Eliciting risk and time preferences." Econometrica 76.3 (2008): 583-618.