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Integrated framework for the external cost assessment of nuclear power plant accident considering risk aversion: The Korean case

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HIGHLIGHTS

- External cost assessment framework for NPP is proposed considering risk aversion.
- VSL was derived from WTP for mortality risk reduction from hypothetical NPP accident.
- RRA was derived to integrate public risk aversion into external cost of NPP accident.
- Individual-level survey was conducted to derive WTP and RRA for NPP accident risk.
- The external cost was estimated considering the direct cost factors of NPP accident.

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ABSTRACT

Recently, the estimation of accident costs within the social costs of nuclear power plants (NPPs) has garnered substantial interest. In particular, the risk aversion behavior of the public toward an NPP accident is considered an important factor when integrating risk aversion into NPP accident cost. In this study, an integrated framework for the external cost assessment of NPP accident that measures the value of statistical life (VSL) and the relative risk aversion (RRA) coefficient for NPP accident based on an individual-level survey is proposed. To derive the willingness to pay and the RRA coefficient for NPP accident risks, a survey was conducted on a sample of 1550 individuals in Korea. The estimation obtained a mean VSL of USD 2.78 million and an RRA coefficient of 1.315. Based on the estimation results in which various cost factors were considered, a multiplication factor of 5.16 and an external cost of NPP accidents of 4.39E−03 USD-cents/kW h were estimated. This study is expected to provide insight to energy policy decision-makers on analyzing the economic validity of NPP compared to other energy sources by reflecting the estimated external cost of NPP accident into the unit electricity generation cost of NPP.

1. Introduction

1.1. Research background

Since the Fukushima Daiichi nuclear power plant (NPP) accident, the estimation of the external cost of an NPP accident within the social cost of nuclear energy has obtained substantial attention. A related issue that arises from environmental damages and its external effects is the internalization of such externalities (Bickel et al., 2005). Electricity generation, especially nuclear energy generation, like other industries is not free from health and environmental impacts. Several of these impacts, where their costs are imposed on society and environment, have traditionally not been accounted for in the market price, in particular the price of electricity.

One of the important external cost to be included in the internalization process is the public health effect from a NPP accident resulting in radioactive material release (OECD/NEA, 2003). The calculations of the economic consequences of a NPP accident requires a series of analysis, including the accident consequence analysis based on a NPP accident scenario and associated probabilities. The conventional approach consists of calculating the expected value of various accident scenarios, calculated as the sum of the accident scenario probabilities multiplied by their

Abbreviations: CDF, Cumulative Distribution Function; CRRA, Constant Relative Risk Aversion; CV, Contingent Valuation; CVM, Contingent Valuation Method; DB, Double-Bounded; DBDC, Double-Bounded Dichotomous Choice; DC-CV, Dichotomous Choice-Contingent Valuation; EUT, Expected Utility Theory; LPZ, Long-Term Planning Zone; MACCS2, MELCOR Accident Consequence Code System 2; MLE, Maximum Likelihood Estimation; MPL, Multiple Price List; PAZ, Precautionary Action Zone; NPP, Nuclear Power Plant; RRA, Relative Risk Aversion; SBDC, Single-bounded Dichotomous Choice; UPZ, Urgent Protective Action Planning Zone; VSL, Value of Statistical Life; WTP, Willingness to Pay

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associated monetary consequences (Markandya et al., 1998; European Commission, 2005; Kim and Kang, 2008; Jang et al., 2011).

However, the main criticism of this approach is that there is a discrepancy between the social acceptability of the risk and the estimated expected value of NPP accident (Nuclear Energy Agency, 2002). Beyond the quantification of the physical impacts on mankind and the environment, some issues regarding the integration of economic indicators such as the monetary value of statistical life (VSL), or risk aversion premium with the expected value of NPP accident consequence have been suggested to be reflected in the estimation of the external costs of the nuclear fuel cycle. Therefore, various valuation methods for the external cost assessment of a NPP accident, including the use of rule of thumbs model and the estimation of risk aversion coefficient based on the risk averse behavior of investors, have been proposed. However, more analytical work on external cost estimation, including monetary valuation of life and the consideration for the public risk perception are needed to support a comprehensive internalization of externalities in the decision making-process for the economic agents or policy makers (European Commission, 2005; Laes et al., 2011).

Therefore, an integrated framework for the external cost estimation of a NPP accident to estimate the value of life for the equivalent fatality following a NPP accident by investigating the willingness to pay (WTP) for a given mortality reduction rate for a hypothetical NPP accident and to quantify risk aversion coefficient based on the structural estimation method is proposed in this study. The main objective of this study are the following: (1) to assess the VSL, is derived from the WTP for a decrease in mortality risks in hypothetical NPP accidents based on the contingent valuation (CV) survey result, (2) to analytically estimate the relative risk aversion (RRA) coefficient, as a measure of public risk aversion to NPP accident, based on the expected utility theory (EUT) by employing multiple price list (MPL) survey design, (3) to derive multiplication factor for estimating the external cost of an NPP accident considering various direct cost factors associated with the NPP accident consequences, and (4) to support decision making processes towards the internalization of the external cost related to NPP accident by reflecting the estimated external cost within the electricity cost of a NPP.

1.2. Literature review

1.2.1. External cost assessment of NPP accident

The externalities of energy refer to the social effects, such as health and environmental impacts, arising from the process of producing the energy, but that are not reflected in the market price of the energy. Especially for the nuclear-generated electricity, the evaluation of the consequences of a NPP accident plays an important role in the reliability and credibility of the overall external costs of nuclear-generated electricity (Nuclear Energy Agency, 2002).

The conventional methodology used to evaluate the impacts of accidental releases is based on analyzing the expected damages caused by NPP accident (Markandya et al., 1998; European Commission, 2005). The estimate is calculated as the summation of the probability of the occurrence of possible accident scenarios multiplied by the corresponding consequences resulting from the accident. In the nuclear energy sector, probabilistic safety assessment (PSA) has served a basis to evaluate the potential causes of the accident, the possible probabilities of occurrence, and the corresponding expected environmental releases. A number of PSA studies have been carried out for different types of reactors in various countries to estimate the external cost of NPP accident based on the expected-value approach. Especially, previous studies in external cost assessment of NPP accident included top-down approach where the cost was estimated based on the historical experience of NPP accident, such as Chernobyl reactor accident (Laes et al., 2011; Hohmeyer, 1988; Ottinger et al., 1990; Rabl and Rabl, 2013), bottom-up approach where the weight of NPP accident risk and consequence calculation was given based on the simplified PSA analysis (Masuhr and Oczipka, 1994; Burgherr and Hirschberg, 2008) or the plant-specific PSA analysis (Hirschberg and Cazzoli, 1994; Wheeler and Hewison, 1994).

An economic analysis of severe accidents in energy sectors often involves assigning monetary values to human lives, which is of particular concern in the case of the nuclear energy because humans may be significantly affected by exposure to radioactive fission products may be released into the environment and may pose a radiation hazard to the local population (Lewis et al., 1979). However, although the risk of fatality resulting from a NPP accident can be identified in physical terms, it is difficult to directly convert the risk of fatality into the health effect cost of the accident because there are no direct market prices for the value of life regarding the equivalent fatality resulting from an accident (Weil, 2001). While there are a number of studies on estimating VSL, the value of the estimated VSL differs on the country, the level of wealth, risk categories, and others (Biausque, 2010; Viscusi and Aldy., 2003). Therefore, a proper method which can estimate the VSL regarding a NPP accident considering the risk characteristics or the risk perception of a specific group of population is needed.

The economic assessment based on expected-value approach as presented above have been challenged by civil society in their inability to reflect risk perception (Markandya, 1994; O'Riordan and Cameron, 1994). It has been recognized that there is a discrepancy between the social acceptability of the risk and the average monetary value which corresponds in principle to the compensation of the consequences, or the cost of expected health impacts, for each individual of the population affected by the accident (Nuclear Energy Agency, 2002). In particular, the expected-value approach has been criticized for ignoring risk aversion and the perceived probability of an accident (Pearce, 2000). Therefore, recent studies have tried to integrate the public risk perception toward NPP accident in the external cost; thus, several methods have been proposed for this purpose.

1.2.2. Public risk aversion towards NPP accident

It has been widely known that the perceived risks are much greater than the expert estimates in the nuclear context (Roth et al., 1990). This phenomena suggests that people do not value risks of group accidents, in which tens or hundreds of deaths occur because of a single accident, in the same way as they value individual deaths although the equivalent fatality from the group accidents are not common and its risk is small compared to other accidents. Especially in the case of NPP accident, previous study found the insignificant relationship between the probability of a disaster and the choice of individuals; that is, the individuals process their perceived risk on the basis of conditional losses from an NPP accident, rather than the probability of an accident (Itaoka et al., 2006). However, it is less obvious how the public risk aversion toward NPP accident can be quantitatively accounted for and reflected into the external cost assessment.

Therefore, there have been various studies which explored the relationship between the risk aversion and the expected value of a NPP accident consequence and proposed a method to take account of risk aversion in the external cost estimation. Early studies have suggested the rules of thumb models for valuing group deaths by considering the probability of an accident and the number of persons affected and derived an implied risk premium based on the proposed rules of thumb model (Ferguson, 1992; Rocard and Smets, 1992; Ascari and Bernasconi, 1997). However, the estimated risk premium for different rules of thumb models differs several