Applied Radiation and Isotopes 67 (2009) 1307–1310

Contents lists available at ScienceDirect

Applied Radiation and Isotopes

journal homepage: www.elsevier.com/locate/apradiso

A step function model to evaluate the real monetary value of man-sievert with real GDP

Seong H. Na[a,*], Sun G. Kim[b,1]

[a] Korea Institute of Nuclear Safety, 19 Guseong-dong, Yuseong-gu, Daejeon 305-338, Republic of Korea
[b] School of Business, Daejeon University, Yong Woon-dong, Dong-gu, Daejeon 300-716, Republic of Korea

ARTICLE INFO

Keywords:
Real monetary value
Economic
Step function model
Aversion factor
Optimization of radiation protection
GDP deflator
Real GDP

ABSTRACT

For use in a cost–benefit analysis to establish optimum levels of radiation protection in Korea under the ALARA principle, we introduce a discrete step function model to evaluate man-sievert monetary value in the real economic value. The model formula, which is unique and country-specific, is composed of real GDP, the nominal risk coefficient for cancer and hereditary effects, the aversion factor against radiation exposure, and average life expectancy. Unlike previous researches on alpha-value assessment, we show different alpha values in the real term, differentiated with respect to the range of individual doses, which would be more realistic and informative for application to the radiation protection practices. GDP deflators of economy can reflect the society's situations. Finally, we suggest that the Korean model can be generalized simply to other countries without normalizing any country-specific factors.

1. Introduction

Although we have applied concepts of economic theory to optimize radiation protection with regard to the recommendations of the ICRP, 1977, quantification of the appropriate monetary value of radiation dose still presents many difficulties in practice.[2] It seems that, under the ALARA (so called Optimization) principle, each country needs to establish a nation-specific model to evaluate its own monetary value.[3]

Setting up a model for the optimization under economic fluctuations would be the first priority. Among various approaches for setting up a model, the human capital approach appears to be more practical than the revealed preference (or willingness to pay (WTP)) approach since the former ensures a country's objective alpha value instantly by plugging its socio-economic variables into a model. Based on the human capital approach, techniques for use in the quantitative optimization of radiation protection include the procedures of cost–benefit analysis.[4] The form of cost–benefit analysis recommended by the Commission involves a balance between the costs of radiation protection and health detriment and all the benefits accruing to society. Various linear models balancing the costs and benefits have been designed in previous literature. Eliminating the measurement problem of the curvature of aversion factor, we introduce a discrete stepwise model which is more practical and simple to apply, since it shows real monetary values according to different levels of exposure. Real monetary value represents the constant value of human life by removing the effects of rising prices on the nominal value.

Most of the terms of the analysis are not only dependent on the level of radiation protection but also on other socio-economic variables. Much research (Schneider et al., 1997, pp. 241–251; Lefaure, 1998, CEPN report) has been done in defining all the parameters and variables employed in the model. We, however, need to be careful to use economic variables, since a single variable has two different values in its real and nominal terms. One of the most crucial variables in cost–benefit analysis is national income, which should be used to calculate a value for a societal life. For most of the previous research, gross domestic product (hereafter GDP) in nominal terms has been used for the national income. It would be valid to use nominal GDP for the economy whose price levels remain reasonably stable. However, for economies with high inflation rates, real GDP incorporating changes of price level has to be used when we need to discuss the transition of man-sievert value in the long run.[5]

---

* Corresponding author. Tel.: +8242 868 0302; fax: +8242 868 0353.
E-mail addresses: shna@kins.re.kr (S.H. Na), sunkim@dju.ac.kr (S.G. Kim).
[1] Tel.: +8242 280 2356; fax: +8242 283 7171.

[2] NCRP Report No. 120 (1994, pp. 16–20).

[3] IAEA (2002, pp. 32–37).

[4] The ICRP has concluded that the phase "as low as reasonably achievable" can be interpreted by a process of cost–benefit analysis which establishes optimum levels of radiation protection and, identified a simple way of the analysis in ICRP publication 26 and this fundamental concept is concisely described in the ICRP-103 (2007).

[5] GDP is the market value of all final goods and services produced within a country during a given time period. There are two ways to measure GDP. Nominal GDP is the value of production at current year prices. For example, the nominal GDP in 1990 ($5803 billion) is calculated using year 1990 prices for goods and services. Real GDP is the dollar value of production using a given base year prices. For example, real GDP in 1990 ($7112 billion dollars in year 2000) is calculated using 2000 prices for goods and services.

0969-8043/$ - see front matter © 2009 Elsevier Ltd. All rights reserved.
doi:10.1016/j.apradiso.2009.02.028

Furthermore, we recommend that the concept of purchasing power parity (PPP) should be adopted if it needs international comparison of alpha values in real terms. That is, PPP GDP has to be applied into the model for cross sectional analysis. Using PPP GDP is arguably more useful because it takes into account the relative cost of living, and inflation rates between countries, rather than just using exchange rates, which have the potential to distort the real differences in income.

The objectives of this paper are to assess the real monetary value for the optimization of radiation protection, which is consistent even under price level fluctuation, and to propose this stepwise model as an alternative which can be generalized simply to other countries without normalizing any country-specific factors.

2. Experiments and results

2.1. A discrete step function model

There are two economic methods to assess the monetary value of a human life: the "human capital approach" and the "revealed preference approach." The former calculates the basic monetary value of the man-sievert related to the monetary value of the potential health effects, while the latter estimates the individual's "willingness to pay" to reduce the risk of death or detrimental effects of the exposure. WTP represents the average amount of money that individuals are ready to pay to decrease a certain risk.[6]

Employing the human capital approach for our model, we can explain that the monetary value of man-sievert is equal to the probability of developing a health effect, multiplied by the monetary value of the effect. For simplicity, health effects are being expressed in terms of number of life years lost, since their monetary values are based on the monetary values given to one year of life or the monetary value of a human life.

To assess the monetary value of human life as corresponds to the loss of an individual's contribution to national wealth, most of the models in the human capital approach start from the relationship between the level of exposure and the monetary value of the health effects under the assumption that they are proportionate each other. That is, they are in a linear relationship, even over a certain dose level as described in the equations below as introduced by ICRP 101 and CEPN as of 1993.[7]

$$\alpha_{ref}(x) = \alpha_{base} \quad \text{for } x < x_0 \tag{1}$$

$$\alpha_{ref}(x) = \alpha_{base} \times \left(\frac{x}{x_0}\right)^a \quad \text{for } x \geqslant x_0 \tag{2}$$

Here, α_{base} denotes the monetary value of the health effects of a unit of dose. That is, α_{base} reflects the value of the expected health effects regardless of the level of individual exposure, and the monetary value of the health effects associated with one man-sievert is considered as constant. It can be calculated by summing the loss of life expectancy and the medical costs induced by a radiation health effect. In the above formula, x_0 is the level of exposure in nature, in which aversion to the dispersion of exposure is not considered. As for lower limit x_0, risk aversion can be considered only beyond a certain minimum exposure level. In the Eq. (2) above, a, the degree of aversion to the dispersion of individual exposure, should be greater than 1.

Table 1
Risk aversion factor "*a*" value by dose level (CEPN).

"*a*" Value	1	1.2	1.6	1.75
Dose level (mSv)	0–1	1–5	5–15	15–50

Note: See Caroline Schieber (2000).

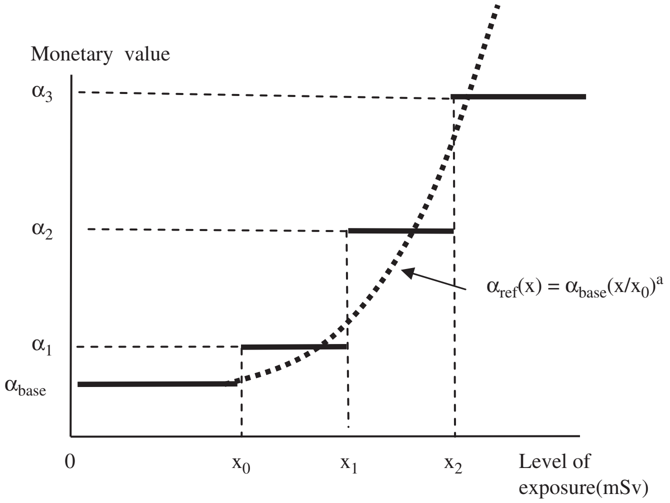

Fig. 1. A step function model.

We are confronted with several problems when applying the above linear model. First, a single exponential function would not be adequate to derive the monetary value which should be valid for all ranges of exposure. As shown in the degree of aversion factor surveyed from the WTP approach, it has a different value by level of exposure.[8]

In this linear relationship, the degree of public aversion has to be surveyed to assess the relevant monetary values of each level of dose. It, however, would not be available to survey the aversion factor at an instant period of time. Therefore, in the case of occupational exposure in France, CEPN reported that a range of aversion values between 1.2 and 1.75 seems reasonable. According to the WTP approach, $a = 1.2$ if the level of exposure is between 1 and 5 mSv/year, $a = 1.6$ if the level is between 5 and 15 mSv/year, and $a = 1.75$ if the level is over 15 mSv/year.[9] (Table 1).

To avoid a measurement problem with the above risk aversion factor, we propose a step function by distribution of dose ranges. We sorted exposures over 1 mSv of an individual dose into three different categories.[10]

$$\alpha_{ref}(x) = \alpha_{base} \quad \text{if } x \leqslant 1 \tag*{(1)$'$}$$

$$\begin{aligned} \alpha_{ref}(x) = {} & \alpha_1 \quad \text{if } 1 < x \leqslant x_1, \\ & \alpha_2 \quad \text{if } x_1 < x \leqslant x_2, \quad \text{and} \\ & \alpha_3 \quad \text{if } x > x_2, \end{aligned} \tag*{(2)$'$}$$

From a graphical point of view, the model is as shown in Fig. 1: the vertical axis shows what it is reasonable to spend to prevent one man-sievert, expressed in monetary units and the horizontal axis shows the individual dose levels in millisieverts.

The reason why we set four different ranges of exposure in Korea is that there is a concrete pattern of distribution of persons

---

[6] Baum et al. (1994, pp. 12–15) and US Nuclear Regulatory Commission (1995, pp. 8–10).

[7] See Caroline Schieber (2000).

[8] Leblanc (1997, pp. 18–20).

[9] See Caroline Schieber (2000).

[10] Kim (2005).