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Optimising risk reduction: An expected utility approach for marginal risk reduction during regulatory decision making

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ABSTRACT

In practice, risk and uncertainty are essentially unavoidable in many regulation processes. Regulators frequently face a risk-benefit trade-off since zero risk is neither practicable nor affordable. Although it is accepted that cost–benefit analysis is important in many scenarios of risk management, what role it should play in a decision process is still controversial. One criticism of cost–benefit analysis is that decision makers should consider marginal benefits and costs, not present ones, in their decision making. In this paper, we investigate the problem of regulatory decision making under risk by applying expected utility theory and present a new approach of cost–benefit analysis. Directly taking into consideration the reduction of the risks, this approach achieves marginal cost–benefit analysis. By applying this approach, the optimal regulatory decision that maximizes the marginal benefit of risk reduction can be considered. This provides a transparent and reasonable criterion for stakeholders involved in the regulatory activity. An example of evaluating seismic retrofitting alternatives is provided to demonstrate the potential of the proposed approach.

1. Introduction

One long-standing theme within regulatory risk management is evaluating the cost–benefit of managing risk. Assuming a risk warrants active management, what is a reasonable spend on risk management; when does this spend become disproportionate to the benefits that a managed risk brings and how far should investment in risk management continue, if at all, beyond the point whereby the risk is deemed insignificant? In essence, this is an optimisation problem inherently bound up with the law of diminishing returns, in that continued investment in risk management results in ever-decreasing incremental reductions in risk of lesser incremental value. Wise risk managers understand that the principal benefits of risk reduction are likely to be secured by targeting resources at a relatively few features of a problem, and that this action will be optimised when the risk is reduced to that which is as low as reasonably practicable (ALARP) or achievable (ALARA). Thereafter, increased investment may become disproportionate to the benefits gained. ALARP and ALARA are well-researched concepts within health and safety legislation, radiation protection, and to a limited extent within environmental protection. ALARP has been controversial and subject to several court rulings; especially with respect to what constitutes a reasonable expectation of investment by a regulated party, and thus the concept of gross disproportionality (of investment in risk management compared with the risk reduction benefits gained). A familiar regulatory discussion involves the regulator and regulated party exchanging views on (i) the initial significance of a risk, thus triggering a risk management action where the risk is deemed significant; followed by (ii) an enthusiastic debate on the practicalities and costs of risk management (often requiring additional investment), which may secures agreement over the residual risk level and degree of investment. What guidance can researchers bring to these debates?

Fig. 1 illustrates the framework the Health and Safety Executive (HSE, UK) has adopted in its regulation process [1]. The inverted triangle represents an increasing level of risk for a particular hazardous activity as we move from the bottom of the triangle towards the top. The regulators' objective is two-fold. Firstly to ensure that the risks do not exceed an unacceptable level, and secondly to ensure that risk management measures put in place to reduce risk are proportionate to the risk. Practically, the degree of risk often falls in the ALARP region, so that benefits are achieved while being prepared to tolerate the risks from the activities. This framework provides a reasonable description of regulatory decision making under risk. However, suppose there are several

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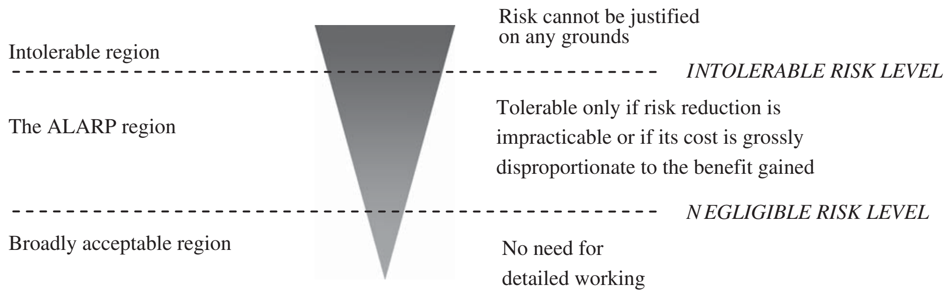

Fig. 1. Optimising risks and benefits. The width of the triangle represents the possibility of risk involves.

feasible solutions to an environmental problem, each of which leads to a degree of residual risk that falls into the ALARP region, for example. How the regulator should choose among these alternatives?

This is the field of options appraisal for risk reduction, of which an economic component is only one aspect. Cost–benefit analysis (CBA) was originally used to evaluate the desirability of governmental intervention in markets, and has now been used in many areas of public decision making. Typical fields of application include transportation [2,3], health care [4,5], environment [6–10], and safety [11,12]. The essential foundations of cost–benefit analysis are as follows: benefits and costs are narrowly defined as monetary values, and an activity is worthwhile only if its benefits exceed its costs. A benefit–cost ratio that is the ratio of total benefits relative to total costs is commonly used as one of the criteria in regulatory decision making. Some important issues on CBA have been widely investigated, for example, uncertainty [13,14], discounting rates [15–17], and equity [18].

Most researchers agree that benefit–cost ratios are neither necessary nor sufficient for the regulatory decisions, partially because economic factors are usually not the most important, and partially because not all important factors for decision making can be quantified [18,19]. In some areas, the regulation of nuclear waste disposal for example, the optimisation of risk reduction in the ALARP region has received considerable attention.

One criticism of cost–benefit analysis is that decision makers should consider marginal benefits, not present ones, in decision making. Marginal benefit is the increase of total benefit as a result of an extra investment in risk reduction. This concept grew out of attempts by economists to explain the determination of price [20,21]. It is often assumed in economics that as the amount of any one input is increased, holding all other inputs constant, the amount that output increases for each additional unit of the expanding input will generally decrease. This law of diminishing marginal utility implies that there exists an optimal amount of input such that the efficiency of the investment is maximized. The objective of marginal analysis then is to find out the optimal solution among those alternatives of investment. Within the context of risk regulation, marginal benefit represents the marginal effect of risk reduction, mathematically the first derivative of the total benefit with respect to the amount of investment, from a range of alternatives. In most scenarios of risk regulation, the possibilities of disaster (risk) can only be reduced to some values above zero and further reduction will be unaffordable. Therefore, marginal analysis can contribute to the optimisation of risk reduction in the ALARP region. We have not found any application of marginal analysis in CBA. The reason might lie in the difficulty of connecting a reduction of risk with monetary values of benefit and cost, especially in the fields of health and safety and environmental legislation where externalities are prominent. Below, we propose an approach that maximizes the marginal benefit of risk reduction by estimating the first-order condition of expected utility. With this approach, different alternatives can be compared according to their efficiencies in reducing risk with least monetary expenditure.

This approach could be a supplement to the framework of ALARP and quantified risk assessment. Applying ALARP requires a comparison of different credible risk reduction strategies in order to demonstrate at what level the risks are optimised. It is difficult to achieve it because we lack criteria on how efficient the risks could be reduced for each risk management option [22,23]. This approach is especially suitable for the comparisons of different risk reduction methods.

2. An expected utility approach of cost–benefit analysis

Expected utility theory has long been an approach to deal with the problem of decision making under risk and uncertainty in economics. The axiomatic hypothesis of expected utility is that the decision maker can make a possibility distribution over possible outcomes of activities. When applying expected utility theory to regulatory decision making, we need to assume that the regulator has a utility function (or preference) over public wealth. This assumption is reasonable because the objective of the regulators is to regulate specific activities on behalf of the public. Note that this assumption is different from the general assumption in economics that the utility function of an agent is the evaluation of his/her own wealth. In economics, individual decision makers are assumed to be self-interested. This assumption is not suitable for the case of regulatory decision making because public welfare is a primary objective. Assuming that the regulator only cares for his/her own benefit in regulation is equivalent to assuming that no regulator can be component.

Suppose an activity may lead to several possible outcomes and each outcome can be expressed as a monetary value. Assume the decision maker has a complete, reflexive, transitive, and continuous evaluation over these monetary outcomes, or in other words, he/she possesses a von Neumann–Morgenstern utility function. Let x be an outcome and let X be the set of possible outcomes. Let p be a simple probability measure on X, thus $p=(p(x_1), p(x_2),\dots,p(x_n))$ where $p(x_i)$ are probabilities of outcome $x_i \in X$ $(i=1,\dots,n)$ occurring. Note that there are finite elements $x \in X$ for which $p(x)>0$, and that $p(x_i) \geq 0$ for all $i=1,\dots,n$ and $\sum_{i=1}^{n} p(x_i)=1$. The expected utility over the set of outcomes X is expressed as

$$U(X)=\sum_{i=1}^{n} u(x_i)p(x_i) \quad (1)$$

where $u(\cdot)$ is the von Neumann–Morgenstern utility function.

Let $\geq_h$ be a binary relation over U so that $X \geq_h Y \Leftrightarrow U(X) \geq U(Y)$, which means that X is preferred to, or equivalent to, Y if and only if $U(X) \geq U(Y)$. Similarly, we have $X >_h Y \Leftrightarrow U(X) > U(Y)$ and