CRR DISCUSSION PAPER SERIES A

Discussion Paper No. A-14

On Environmental Risk Management: The Interactions of Economic and Non-economic Factors

Yasuhiro SAKAI

April 2015

Center for Risk Research
Faculty of Economics
SHIGA UNIVERSITY

1-1-1 BANBA, HIKONE,
SHIGA 522-8522, JAPAN

On Environmental Risk Management: The Interactions of Economic and Non-economic Factors*

by Yasuhiro Sakai

Emeritus Professor, University of Tsukuba & Shiga University

Abstract

This paper aims to discuss environmental risk management from a new perspective. Although there is a growing literature dealing with the relation between the economy and the environment in the absence of risk and uncertainty, it is quite unfortunate that the effects of a variety of risk factors on such a relation have not been intensively investigated by social scientists.

Before 11 March 2011, most people believed in the myth of absolute safety. Since the Great East Japan Earthquake took place, however, their concept of risk for nuclear power generation has been changed completely. What they once regarded as the unthinkable events is no longer beyond imagination. This clearly indicates the necessity of studying environmental risk management in a new perspective.

In this paper, we would like to show that simple applications of the conventional expected utility theory would possibly lead us to wrong conclusions. It is high time for us to combine both economic and non-economic (cultural and psychological) factors towards a more synthetic theory of decision making under risk and uncertainty.

Key words: Environment, risk management, non-economic factors, nuclear power plant

---

＊ Financial support from the Japanese Ministry of Education, Culture, Sports, Science and Technology through Grant-in-Aid for Scientific Research (C) No. 25512010 is gratefully acknowledged. Thanks are also due to Mr. Masashi Tajima and staff members of the Risk Research Center, Shiga University for editorial assistance. All remaining errors are solely my responsibility.

1. Introduction

The purpose of this paper is to discuss environmental risk management from a new perspective. We are especially concerned with the relationship among the following three key concepts: Risk, the economy, and the environment. It is true that there is a growing literature dealing with the last two in the absence of risk and uncertainty. [1) We would like to note, however, that the introduction of risk factors would probably cause a drastic change for the conceptive framework and analytical tools.

First of all, we have to discuss what risk is all about. In historical perspective, there exist two different concepts of risk —— old and new. [2) In old times, the following four were the most fearful items in Japanese people's mind:

"Earthquake, lightning, fire and arrogant father".

Japan is a rather small yet beautiful country. It is a long archipelago spreading from the sub-arctic area to semi-tropical zone: It is surrounded by so many seas and contains so many volcanoes and hot springs. And as the old saying goes, the Japanese people have experienced so many earthquakes, so many lightning, and so many fires since the beginning of time. However, fearful fathers are now almost non-existent, thus being replaced by friendly papas.

Time has changed so drastically since then. In modern times, we have to deal with new kinds of risk factors. Among these new factors, the following four items may be very conspicuous:

"Radioactivity, global warming, garbage and AIDS".

As we can see, it appears that the old set of risk items are so different from the new set. Surely, there are some gaps between these two sets. It should be noted, however, that those gaps have been wiped out by the historic great earthquake that hit the Tohoku region four years ago.

In 11 March 2011, the Japanese nation marked the fourth anniversary of the 2011 Great East Japan Earthquake, which was characterized as the combination of the three great evils: great earthquake, great tsunami and great nuclear plant accident. It was also the unique union of old and new concepts of risk above-mentioned: earthquake and radioactivity. More than 18,000 people died or remain missing following the disaster, which have completely devastated much of the Tohoku region. Remarkably, the dreadful nightmare still continues at Tokyo Electric Power Company's Fukushima No.1 nuclear plant, which already suffered three reactor core meltdowns and remains plagued daily by increasing amounts of radioactive water.

Before the Great Earthquake happened, most people believed in the *myth of absolute safety*: they regarded a nuclear power plant as a sort of accident-free, dream-like facility. They were told that the nuclear facility could bring them a ideal set of cheap cost, stable power supply, more jobs, and above all absolute safety. However, the reality is sometimes more cruel than the fiction: The tragic disaster really happened in the Tohoku region four years ago. Since then, people's concept of risk for nuclear power generation has been changed completely. What they once regarded as the unthinkable event is no longer beyond imagination. There should be no "black swans" in scientific mind. In my opinion, this clearly indicates the necessity of studying the main subject of this paper in a new perspective: environmental management under risk and uncertainty. [3)]

The outline of this paper is as follows. Section 2 will set up the general framework for decision making when environmental risks are present. Section 3 will introduce dreadful risks, discussing the effects of non-economical (psychological and cultural) factors on individual decision making. In section 4, we will distinguish between measurable risk and non-measurable uncertainty, thus exploring the determination of the optimal project under true uncertainty. Concluding remarks will be made in section 5.

2. Decision Making under Environmental Risk: The General Framework

We are concerned with individual decision making. In the absence of risk and uncertainty, the relationship between a person's act and its outcome is clear and straightforward. For instance, let us consider a bread factory in which a certain amount of flour combined with a certain amount of labor produces a certain amount of bread. If both the labor and the land are ignored, then the relation between flour and bread is simply described by the production function: F(flour) = bread.

In contrast to such a simple world, the introduction of risk and uncertainty would make the correspondence between human act and outcome considerably complex. It is rather common that a single act yields several outcomes. Presumably, which one among those outcomes will really come out depends on the state of the world. Let us take a example of farming. While a given amount of rice planting in June is supposed to produce a flexible amount of harvest in October. Whether the harvest is good or bad cannot be foreseen by the farmer . Although the good weather produces the good harvest and the bad weather the bad harvest, the weather condition between planting and harvesting is generally unpredictable and perhaps beyond human power of

Table 1 The decision problem under risk: The general framework

alternative choices	states of the world s_1	$\cdots$	s_j	$\cdots$	s_n
a_1	y_{11}	$\cdots$	y_{1j}	$\cdots$	y_{1n}
$\vdots$	$\vdots$		$\vdots$		$\vdots$
a_i	y_{i1}	$\cdots$	y_{ij}	$\cdots$	y_{in}
$\vdots$	$\vdots$		$\vdots$		$\vdots$
a_m	y_{m1}	$\cdots$	y_{mj}	$\cdots$	y_{mn}
probability	p_1	$\cdots$	p_j	$\cdots$	p_n

knowledge. It would be safe to say that in the world of risk and uncertainty, the relationship between planting and harvesting is described by the following correspondence: F(planting, good weather) = good harvest, F(planting, bad weather) = bad harvest.

Let us discuss a general framework for the decision problem under risk. Formally speaking, as is seen in Table 1, let us denote by a_i (i = 1,..., m) the set of all possible choices by the individual, and by s_j (j = 1,..., n) the set of all possible states of the world. The basic characteristic of these states of the worlds is that the individual has no control whatever over which s_j will occur: In other words, he/she is not informed at all in advance which s_j actually does occur. [4]

When the individual has chosen a specific a_i, and when a specific state s_j is revealed, such a combination (a_i, s_j) yields a specific outcome for him. More formally, the outcome depends on both a_i and s_j, and thereby denoted by y_{ij} (i = 1, ..., m; j = 1, ..., n). We assume that the probability that any particular state s_j actually occurs is denoted by p_j.

Summing up, a general framework of the decision problem is described by the payoff matrix (y_{ij}) with choice vector (a_1, ..., a_m) and state vector (s_1,..., s_n). The probability vector (p_1, ..., p_n), where $p_1 + ... + p_n = 1$, is found in the last row in Table 1.

Table 2 The allocation problem of a thermalpower plant: The city or the country?

alternative choices	states of the world non-accident	accident
the city	2	−2
the country	1	−1
probability	$1-p$	p

We are now in a position to focus on the more specific allocation problem of a thermal power plant. In modern times since the industrial revolution, people have benefited a great deal from the effective use of electricity. In order to meet additional demand for electricity, suppose that we are going to construct a new thermal power plant. As in Table 2, there are only two allocation choices available: the densely populated city or the depopulated country. The thermal power plant is not an absolutely safe facility and may break down because of an accident. We assume that there are two states of the world: The state of non-accident and the one of accident, with the rate of accident being p.

The construction of a thermal power plant in the city area is regarded as the one of 'high return and high cost.' On the one hand, if no accident occurs, then residents can enjoy the benefit of the short distance from the place of power supply to the one of power demand: A shorter distance is expected to contribute to a less transmission cost. We assume that the payoff of the pair (the city, non-accident) is as great as 2 (see Table 2). On the other hand, the thermal power plant may cause air pollution and noise in the neighborhood. Besides, once any kind of plant accident in the urban area occurs, the resulting damage would be very serious, possibly causing even human casualties. Therefore the payoff of the pair (the city, accident) may be (−2), definitely a negative value.

In stark contrast to the above, the construction of a thermal power plant in the countryside can be regarded as the one of 'low return and low cost.' In the case of non-accident, the net benefit will surely be positive yet small since the power transmission to the consumption area will be fairly expensive : So the payoff is assumed to be 1. In the case of accident, the resulting damage would be relatively small: Presumably, the payoff is (−1).

We live in the world of risk and uncertainty. The knowledge of the natural environment is limited, and the security of a thermal power plant per se is not perfect. We have to make our decision making under imperfect information. When we face the payoff matrix of the plant as shown in Table 2, we must do the best possible judgment subject to the technological and informational constraint. Which is a better allocation for the power plant , in the city or in the countryside? No doubt, this constitutes a very important question of environmental risk management.

In order to find the best possible choice among several candidates, it is necessary for us to introduce a particular form of *judgment criterion*. In the field of the modern economics of risk and uncertainty, perhaps the most fashionable criterion is provided by the *expected utility rule*, which was first introduced into moral science very long time ago by Daniel Bernoulli (1738), a very famous Swiss mathematician. [5)]

Let us note that the level of expected utility brought by a choice a_i is given by

$$\begin{aligned} EU_i &= \Sigma_j \; p_j U(y_{ij}) \\ &= p_1 U(y_{i1}) + \dots + p_j U(y_{ij}) + \dots + U(y_{in}) \, . \end{aligned} \qquad (1)$$

Then the expected utility rule is stated as a lucid rule by which we have to make the best possible choice in the sense that the act yielding the maximum value among those expected utilities $EU_1, \dots, EU_i, \dots, EU_m$ is chosen. In other words, we are really engaged in doing the following maximizing operation:

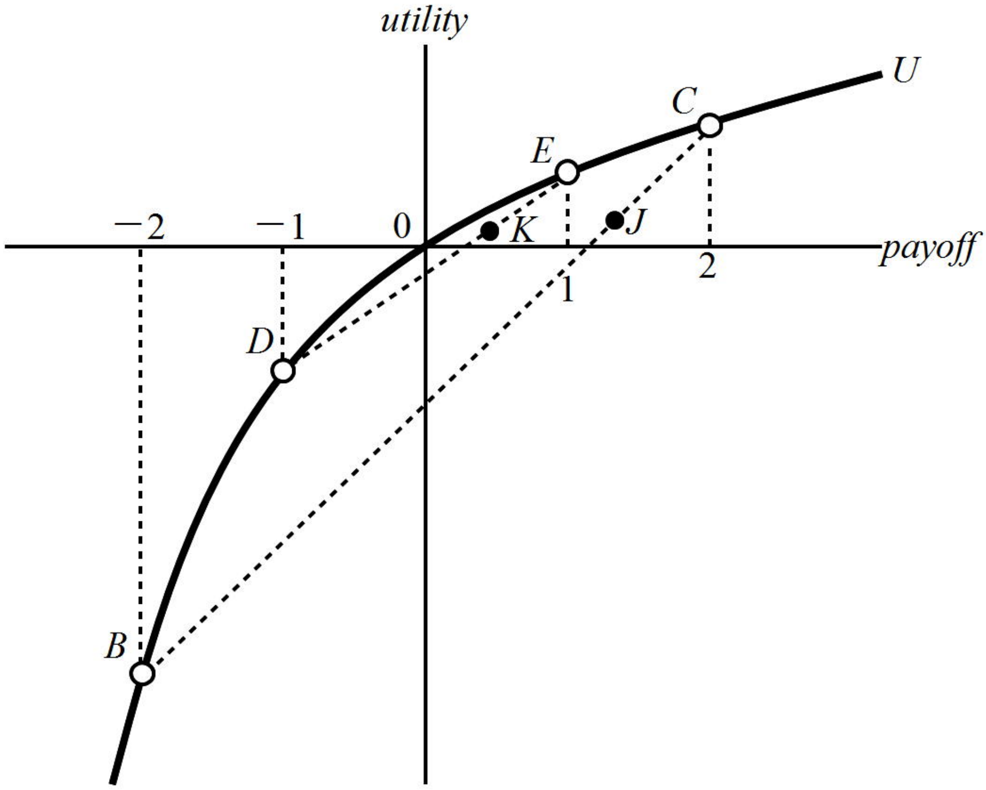
$$\mathrm{Max}_i \; EU_i = \mathrm{Max}_i \; \{ \Sigma_j \; p_j U(y_{ij}) \} \; . \qquad (2)$$

As the saying goes, the proof of the pudding is in the eating. Let us get back to the allocation problem of a thermal power plant mentioned above. Then we find that the levels of expected utility attainable from the construction of the plant in the city and in the country are respectively given by

$$EU(\text{city}) = (1-p)\, U(2) + p\, U(-2) \, , \qquad (3)$$
$$EU(\text{country}) = (1-p)\, U(1) + p\, U(-1) \, . \qquad (4)$$

The question of much interest is which one gives us a greater value, EU(city) or EU(country). The answer should be like this: It depends. It really depend upon the shape of the utility function U, the rate p of accident and several other factors. As

Figure 1　Where do we allocate a thermal power plant,
the city or the country?



can clearly be seen in Figure 1, the greater the degree of risk aversion or the value of the rate of accident, the more likely do they select the countryside as a cite for the thermal power plant.

The allocation problem of a thermal power plant is depicted in Figure 1. For the sake of presentation, let us put $p = 1/5$, a larger value than usual. Then the point J on the line segment BC ,and the point K on the line segment DE respectively indicate the value of EU(city) and EU(country). Note that $BJ : JC = DK : KE = 4 : 1$. Since K is located higher than J, we can conclude that the country is a better plant cite than the city. Needless to say, exactly the opposite conclusion would come if K is located lower than J, which is another possible conclusion under other circumstances.

2. The Presence of Dreadful Risk and the Effects of Non-Economic Factors

As we have discussed above, when we deal with a number of problems associated with environmental risk management, the application of the conventional expected utility theory would clearly very powerful in finding reasonable solutions. In general, we have no objections against such a rule. It is also obvious, however, that the rule is not almighty: There exist many other important exceptions in social science.

First of all, we have to keep in mind that the utility function which is very commonly used in any microeconomic textbook has no solid scientific and objective foundation. In my opinion, it must be a very personal and subjective character, being different person to person. The man who displays a stronger aversion to risk, the concavity degree of his/her utility curve will be greater. Even if we are dealing with the same person, the stability of his/her utility curve will not be guaranteed: The utility curve may shift upward or downward, depending upon his/her feelings and psychology. On the one hand, some persons would possibly feel high by engaging in gambling, and thus shift their utility curves upward. On the other hand, there might exist some other persons who feel frightened before some dreadful risks, and shift their utility curves downward.

Secondly, regarding environmental risks, the amount of damage and the rate of accident may have no objective support, possibly differing person to person. For instance, let us consider the case of environmental damage caused by the construction of a dam. Then probably, the dam constructer in question has a tendency to underestimate the amount of possible damages and the rate of accident per se. As a result, there would emerge a considerable perception gap between the constructor and the general public.

Taking account of these points aforementioned, we see that when dreadful risks and/or psychological and cultural factors are present in human minds, both the utility function and the accident rate are no longer stable, and indeed may change upward or downward. The simple application of the conventional expected utility theory would possibly lead us to come to wrong conclusions. So it is high time for us to combine both economic and non-economic factors towards a more synthetic theory of decision making under risk and uncertainty. There exist several attempts to further generalize the established expected theory in the academic profession. One of these attempts may be stated as the *generalized expected utility theory* to be explained below. [6)]

In a more general framework work than the traditional one, the utility function is not the function of a single variable y, but rather the function of the two variables:

an independent variable y and a shift parameter β; therefore we have the new utility function $U = U(y;\ \beta)$. On the one hand, when people feel excited in gambling, the value of β is expected to increase, which will shift the utility curve upward. On the other hand, if they are mentally horrifying in front of dreadful risks, the value of β will decline, whence the utility curve will shift downward. [7)]

There is one more thing to say. When we are talking about the evaluation of risk frequency, we should not simply take account of probability p per se, but rather its weighted value $\omega(p)$, namely the value obtainable by further filtering p through ω. Since people have a tendency to attach the greatest importance to 100 % safety, the distance between $\omega(1)$ and $\omega(0.9)$ will psychologically be greater than 0.1 in people's minds. Besides, when people are forced to do decision making under dreadful environmental risk, it is highly likely that they do not believe in the official rate p of accident which is announced by the government authority. In such a situation, the weighed value $\omega(p)$ will probably be greater than p per se.

Now let us return to Table 1. If the payoff matrix of payoff of an individual is given as in this table, it is possible to calculate the *weighted value* of his/her choice a_i in the following manner:

$$\begin{aligned} WV_i &= \Sigma_j\ \omega(p_j)\, U(y_{ij};\ \beta_i) \\ &= \omega(p_1)\, U(y_{i1};\ \beta_i) + \ldots + \omega(p_j)\, U(y_{ij};\ \beta_i) \\ &\quad + \ldots + \omega(p_n)\, U(y_{in};\ \beta_i) \end{aligned} \tag{5}$$

Then the *generalized expected utility rule* or *weighted value rule* requires that we make the best possible choice in the sense that the act yielding the maximum value among these weighed values $WV_1, \ldots, WV_i, \ldots, WV_m$ is chosen. That is to say, we are interested in doing the following maximizing operation:

$$\mathrm{Max}_i\ WV_i = \mathrm{Max}_i\ \{\Sigma_j\ \omega(p_j)\, U(y_{ij};\ \beta_i)\}\ . \tag{6}$$

Let compare the two equations (2) and (6). Then we will be able to immediately understand that economic factors and non-economic factors are now delicately intermingled. Decision under risk and uncertainty has to be made by an ordinary man with feelings and fears, not simply by economic man with cold-blooded calculation.

Now for an instance, let us consider the case in which the construction of a power plant at the designated place is planned. Concerning the type of the plant, there are two options: a thermal power plant and a nuclear power plant. As is shown in

Table 3　Alternative types of a power plant:　Thermal or nuclear ?

alternative types of a power plant	states of the world: non-accident	states of the world: accident	psychological factors
thermal	2 prob. $(1-p)$	-3 prob. p	not effective
nuclear	4 prob. $(1-p)$	$-(5+\alpha)$ prob. p	strong aversion to radioactivity

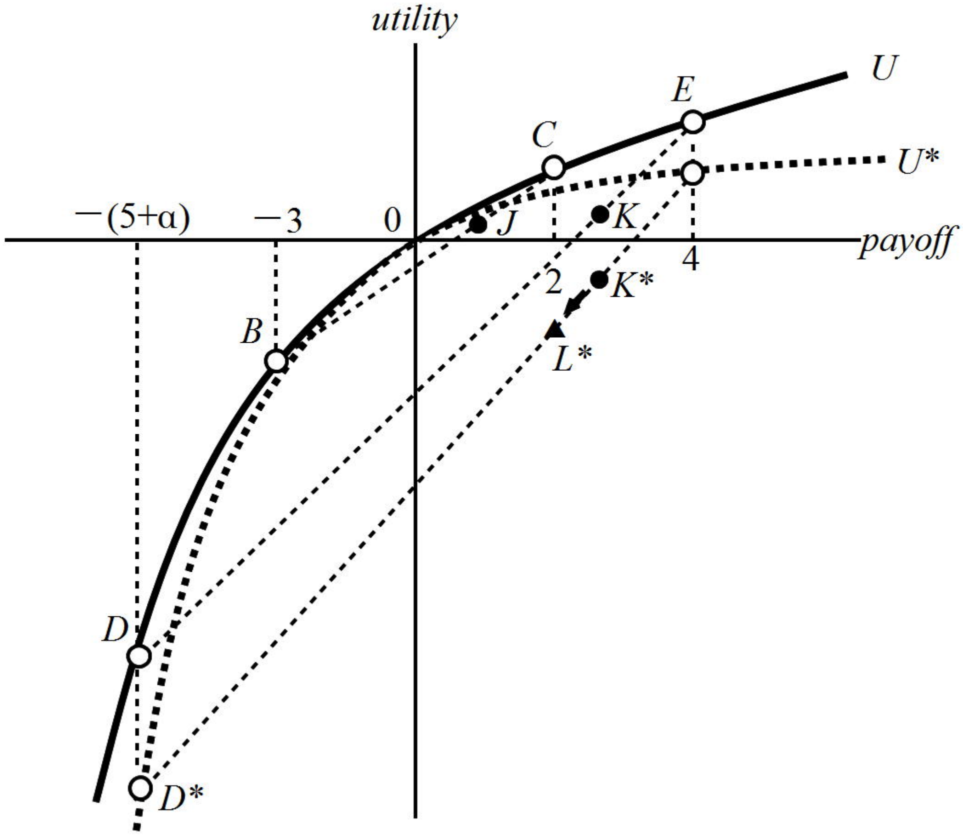
Table 3　the two states of the world are considered here as before:　the state of non-accident and the one of accident. [8)]

We would naturally expect that the rate of accident differs between the two types of power plants.　Let us denote the rate of accident of a thermal power plant by p , and the one of a nuclear power plant by q .　According to the official view of the government authority, q is estimated to be considerably lower than p .　Local residents, however, may have some objections against such an estimate.

As is seen in Table 2, on the one hand, the thermal power plant is assumed to give us the payoff　2 if no accidents occur, and (-2) if an accident occurs.　On the other hand, the nuclear power plant is supposed to be economically efficient than the thermal one, presumably yielding a handsome amount of payoff　4.　Remember that the effects of the nuclear facility are always double-edged.　Schumacher (1973) once paid special attention to such knife edge situation, thus inventing before us the remarkable phrase ' nuclear energy ――salvation or damnation?'　Once the nuclear power plant suffers a serious accident,　the resulting damage would possibly be devastating:　it will estimated to at least (-5) , and the 'plus α ' factor that represents the additional non-measurable damages. [9)]

Let us see what will happen if we dare to mechanically adopt the conventional expected utility theory.　Then we can easily calculate the value of the expected utility attainable from the thermal power plant, and the one associated with the nuclear power plant :

Figure 2　The thermal power plant versus the nuclear power plant:
People may display strong risk aversion to radioactivity



$$EU(\text{thermal}) \quad = \quad (1-p)\ U(2) + p\ U(-3), \tag{7}$$

$$EU(\text{nuclear}) \quad = \quad (1-q)\ U(4) + q\ U(-(5+\alpha)). \tag{8}$$

In Figure 2, the utility curve U represents the reference point for our analysis. For the sake of convenience, let us assume that the rates of accident are considerably larger than realistic : we simply put $p = 1/5$ and $q = 1/10$. Then while the ratio of line segment BJ to line segment JC is given by 4:1 , the rate of DK to KE is 9:1 .

The positions of the two points J and K respectively indicate the value of EU(thermal) and EU(nuclear). Figure 2 shows the case in which K happens to be located higher than J. Therefore if we simply apply the established expected utility theory to such a situation, then we would too quickly come to the conclusion that the nuclear power plant is a better facility. However, some people would have strong objections against this "simple-minded conclusion." We have so far repeatedly stated that so many people have non-measurable fears for dread risks associated with nuclear power generation. This is particularly true in Japan, where so many people have suffered so much by the explosion of atomic bombs in the Second World War. Understandably, peoples' risk aversion for nuclear power continues to be strong, and their trust level for the government policy might be far from satisfactory.

It is now high time that we go beyond the conventional expected theory by introducing non-economic (psychological and historical) factors, so that we will be able to establish a more comprehensive decision theory —— a generalization of the expected utility theory toward a new framework. When adopt such a newly expanded type of decision theory under risk and uncertainty, we can find the weighted values of the two power plants in the following manner:

$$WV(\text{thermal}) = \omega(1-p)\,U(2\,;\beta) + \omega(p)\,U(-3;\beta), \tag{9}$$
$$WV(\text{nuclear}) = \omega^*(1-q)\,U(4\,;\beta^*) + \omega^*(q)\,U(-(5+\alpha)\,;\beta^*)\,. \tag{10}$$

Honestly speaking, as far as the thermal power plant is concerned, the psychological factor is not so effectively working, hence the conventional expected utility theory is still applicable as before. If this is the case, then the influence of β on U may be neglected, and the weighted-value function ω(p) may be reduced to the most simple form of linear function; therefore, Eq. (9) is really equivalent to Eq. (7) above.

The same story should not be applied to the nuclear power plant, however. The difference between conventional and nuclear power generations cannot be overemphasized. Everywhere in the world, and especially in Japan, people have strong feeling against use of nuclear power. Hence it would be quite natural for us to think that such strong fear causes a downward shift of the utility function from U and U^*. Then in Figure 2, the 'new' point of evaluation is K^*, which is located lower than point J, the point of evaluation for the thermal power plant.

Interestingly enough, this is not the end of our story! Note that the new point K^* is now located lower than the horizontal axis, meaning that the nuclear plant per se might be regarded as harmful rather than beneficial. Moreover, if people do not trust much the nuclear policy of the government and tend to think that the 'true' rate of nuclear accident $\omega^*(q)$ substantially exceeds the 'officially announced' rate q ,then the point of evaluation for nuclear power generation would be further downward, possibly reaching the point L^* down below .

It would be pretty fairy to say that the above illustration by Figure 2 is of a very special type, perhaps being a bit far from satisfactory. We would honestly admit the limitation of our simple graphical analysis. However, we must understand that the introduction of non-economic (psychological or cultural) factors into our analysis would drastically change the whole story of the existing literature on nuclear power generation. This is really a very important point. We believe that the results of our analysis taken here are fundamentally robust, and can have applications to many other problems.

3. Selection of the Optimal Project: The World of True Uncertainty

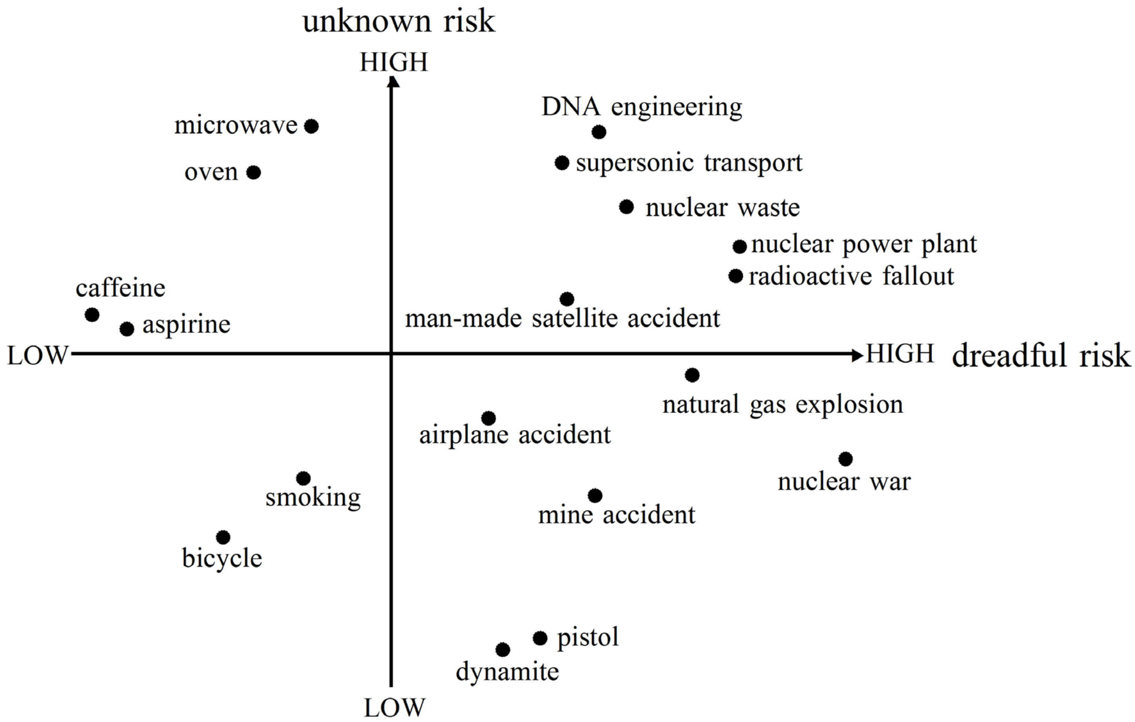
When we are dealing with the problems of environmental risk management, we sometimes wonder if the risks under consideration are really numerically measurable. For one thing, the probability that a certain state occurs may be too ambiguous to be represented by any numerical value. For another, the two states of the world are not clearly distinguishable between them. Therefore, it is necessary but not sufficient to consider the *quantity* of risk only. Due considerations of the *quality* aspect of risk should be the next task of our risk analysis. [10)]

In his famous paper on psychology, Paul Slovic (1987) reported the results of his empirical research on many risk perceptions of American people. The list of 18 items adopted by him is as follows:

> "Nuclear power plant, radioactive fallout, nuclear waist, DNA engineering,
> supersonic transport, man-made satellite accident, nuclear war,
> natural gas explosion, mine accident, airplane accident, pistol, dynamite,
> microwave, oven, caffeine, aspirin, smoking, bicycle."

Slovic attempted to classify these risk items in terms of *unknown risk* and *dreadful risk.* His research results were edited and summarized in Figure 3. As can easily expected ,while nuclear power plant is not unknown risk, it is indeed very dreadful risk. In contrast, DNA engineering represents unknown risk rather than dreadful risk. Microwave has the characteristic that its risk is not dreadful but unknown. Bicycle is regarded as a quite safe means of transportation since its risk is well-known and not dreadful at all.

Figure 3　Unknown risk versus dreadful risk:　The quality of risks



The history of economic thought tells us that there were a few distinguished economists who dared to investigate the problem of risk and uncertainty. Frank Knight was among those exceptional scholars. In fact, in his famous book, Knight (1921) remarked:

"Uncertainty must be taken in a sense radically distinct from the familiar notion of risk, from which it has never been properly separated. ... A measurable uncertainty ... is so far different from an unmeasurable one that it is not in effect an uncertainty at all."

According to Knight, what we usually call risk can be measured: The attached distribution function is no more than its typical numerical representation. In a sharp contrast to risk, uncertainty is basically not measurable at all. In my opinion, the concepts of psychological risks involving unknown and dreadful risks are of non-quantity type, so that they should be included in the general category of uncertainty.

Table 4　Alternative scenarios under uncertainty:　The general framework

alternative projects	s_1	$\cdots$	s_j	$\cdots$	s_n
a_1	y_{11}	$\cdots$	y_{1j}	$\cdots$	y_{1n}
$\vdots$	$\vdots$		$\vdots$		$\vdots$
a_i	y_{i1}	$\cdots$	y_{ij}	$\cdots$	y_{in}
$\vdots$	$\vdots$		$\vdots$		$\vdots$
a_m	y_{m1}	$\cdots$	y_{mj}	$\cdots$	y_{mn}

(scenarios: s_1 … s_n)

So much as the general discussion of uncertainty against risk. We are now ready to turn to the more interesting and more realistic situation in which we have to choose the optimal one out of the set of many projects when no probabilities are attached to the scenarios we think of.

Suppose now that we are facing the environmental uncertainty indicated by Table 4. There are m different *projects* that can be adopted, and n distinctive *scenarios* available. If we take account of all the combinations of the pair (projects, scenarios), then we are able to have the $m \times n$ *payoff matrix*.

Let us make comparisons between the two tables——Table 1 associated with decision making under measurable risk, and Table 4 related to decision making under non-measurable uncertainty. Then we see that there are several points worthy of special attention. First of all, states and scenarios are entirely different concepts. Although each state s_j has its own probability p_j, no numerical probability is attached to any scenario . Second, while any two states are independent and exclusive, this may not be true for scenarios: One project and another project may be partly "overlapped" since their boundaries are ambiguous and not clearly defined. We can see a number of optimistic and pessimistic scenarios that have no solid objective foundations. Third, the selection of scenarios is more or less arbitrary, so that some "gaps" between a pair of them is conceivable.

Now let turn back to Table 4. There are m projects: $a_1, \ldots, a_m$. In order to select the optimal one out of these projects, it is necessary to introduce some forms of selection rules. Specifically, we will consider the following three rules.

The first rule of selection is to simply obey the *average rule*: *we* have to select such a project that it maximizes the average value of payoff. Let us write

$$\mathrm{Ave}_i \;=\; \Sigma_i \; y_{ij} \;/\; n = \;(y_{i1} + \dots + y_{ij} + \dots + y_{in}) \;/\; n \,. \qquad (11)$$

Then the average rule requires that the project yielding the maximum value should be chosen:

$$\mathrm{Max}_i \; \mathrm{Ave}_i \;=\; \mathrm{Max}_i \;\{\; \Sigma_j \; y_{ij} \;/\; n \;\} \,. \qquad (12)$$

This rule is apparently based on the common sense: The middle-of-the road course may often be the golden path in a uncertain world.

The second rule of selection is what we call the *maximax rule*. It distances itself from the middle-of-the road and takes a very optimistic and even aggressive course: We dare to seek the 'very-best-of-the-best targets.' According to this rule, we have to first pick up the best scenario for every possible project, and then proceed to choose the very best project out of these selected projects. Let us write

$$M_i \;=\; \mathrm{Max}_j \;\{\; y_{i1}, \dots, y_{ij}, \dots, y_{in} \;\} \;. \qquad (13)$$

Then the maximax rule says that the project giving the maximum value must be selected:

$$\mathrm{Max}_i \; M_i \;=\; \mathrm{Max}_i \;\{\; \mathrm{Max}_j \; y_{ij} \;\} \qquad (14)$$

The third rule of selection is named the *maximin rule*, representing a more prudent and even defensive behavior. We must first think of the worst possible scenario for every project, and proceed next to find the 'best' one out of these worst scenarios. Let us define

$$N_i \;=\; \mathrm{Min}_j \;\{\; y_{i1}, \dots, \; y_{ij}, \dots, \; y_{in} \;\} \;. \qquad (15)$$

Then the maximin rule requires that the project yielding the maximum value must be chosen:

$$\mathrm{Max}_i \; N_i \;=\; \mathrm{Max}_i \;\{\; \mathrm{Min}_j \; y_{ij} \;\} \,. \qquad (16$$

Table 5　Alternative highway projects under uncertainty:
How to choose the best one

alternative projects	scenarios I	II	ave.	max.	min.
A	6	−2	2	6	−2
B	8	−6	1	8	−6
C	2	0	1	2	0

These three rules of selection above-mentioned are different for each other, and may lead us to obtain entirely different conclusions. In order to understand this important point more clearly, let us look at the three alternative highway projects (Projects A, B and C) with two opposite scenarios (Scenarios I and II). Let us take a look at Table 5.

Project A represents a large-scale development project in which a super highway with affiliated lodging facilities is to be constructed on a partly deforested area. We can have either an optimistic scenario (Scenario I) or a pessimistic one (Scenario II), depending on the business conditions and more personal philosophies. Under Scenario I, this project is expected to yield a handsome amount of money (the payoff is as big as 6). Under Scenario II, the cost of environmental destruction will be heavy and exceed the expected benefit (the payoff is minus 2).

Project B is more aggressive than Project A. It is indeed a super grand-designed project which includes an attractive golf course in addition to all the plans of Project A. If everything is going well (Scenario I), the project will yield a further increase in revenue (the payoff is 6). If something is going against us because of enormous deforestation together with very poor golf revenue (Scenario II), however, it will impose extra burden on us (the payoff is minus 6).

In comparison with these two projects aforementioned, Project C is a very modest and even defensive project. The philosophy behind the project is natural preservation: The small-scale facilities such as walking trails and camping places are all we want to have. While Scenario I will bring us a small benefit (the payoff is 2), Scenario II will yield a negligible amount of loss (the payoff is assumed to be zero).

The question of much interest would be which project is likely to be adopted. The answer should be like this: It depends. It really depends on the life philosophy and ethical judgment of local residents. As is seen in Figure 4, Project A will be adopted by the eclectic average rule, Project B by the aggressive maximax rule, Project C by the prudent maximin rule.

We live in an uncertain world. The long human history teaches us the effectiveness of the safety-first principle. The nature is too big for us to control. As Terahiko Terada (1934), a famous scientist and essay writer, once remarked:

"A natural disaster will repeat itself on a forgetful mind."

It would be very interesting to see whether and to what extent the old warning of Terada remains effective even today.

4. Concluding Remarks

More than 40 years ago, Kikuo Iwata, then one of the rising stars in Japanese economic profession, honestly remarked:

"I have so often been asked: 'What do modern economists think of nuclear power generation? What on earth are they doing now?' ... I myself have never been duly responded to such an important question."

Although Iwata' remark was clear and correct, it was destined to be forgotten soon. When I published *The Economics of Uncertainty* in 1982, I never touched upon the subject of the relationship between nuclear power generation and modern economics. One of the reasons of such neglect was that people believed in the myth that nuclear power was an absolutely safe facility. Needless to say, such a myth has been completely broken since the Great East Japan Earth Quake.

There is one more thing to add. Environmental management under risk and uncertainty , which includes the economics of nuclear power generation as its part , is still a young and underdeveloped area. We believe that there remain so many problems which will be left for future research.

Michio Morishima is probably the most famous economist Japan has ever produced since the World War Ⅱ.[11] In his popular book (1999), he remarked:

"This book 〔his popular book〕 represent what I once called *Symphonic Economics*, namely a sort of interdisciplinary and comprehensive research in social sciences, where economics, sociology, education, history and related field are all present and unified into one. It is such an ambitious project that I have had a strong desire to promote for a very long time."

In writing this book, I have just followed the *Morishima spirits* : I myself have attempted to adopt a symphonic economic approach to environmental risk management under risk and uncertainty. No doubt, in order to complete our mission, another long time will have to go by . Life is a challenge! We should have enough courage and strong will for doing such a new research.

References

Arrow, K. J. (1970) *Essays in the Theory of Risk-Bearing*, North-Holland.

Bernoulli, Daniel (1738) "Specimen Theoriae Novae de Mensura Sortes, " *Commentarii Academiae Scientiarum Imperiales Petropolitanae*, Vol. 5. English translation: Sommer, L. (1954) "Exposition of a New Theory on the Measurement of Risk," *Econometrica* Vol. 22(1).

Bernstein, P. L. (1996) *Against the Gods: The Remarkable Story of Risk*, John Wiley & Sons, Inc.

Borch, K. H. (1968) *The Economics of Uncertainty*, Princeton Univ. Press.

Boulding, K. E. (1968) *Beyond Economics*, Univ. of Michigan Press.

Diamond, P. and Rothschild, M. (1978) *Uncertainty in Economics: Readings and Exercises*, Academic Press.

Hey, J. D. (1979) *Uncertainty in Microeconomics*, New York Univ. Press.

Ikeda, S., Sakai, Y. and Tawada, M. ,eds. (2004) *Risk, the Environment, and the Economy*, Keiso publishing Co.

Iwata, K. (1981) "What are modern economists doing now?," *The Science of Thought*, No. 10.

Kahneman, D. and Tversky, A. (1979) "Prospect Theory: An Analysis of Decision under Risk," *Econometrica* Vol. 47.

Kahneman, D., Slovic, P. and Tversky, A. (1982) *Judgment under Uncertainty: Heuristics and Biases*, Cambridge Univ. Press.

Keynes, J. M. (1921) *A Treatise in Probability*, Cambridge Univ. Press.

Knight, F. H. (1921) *Risk, Uncertainty and Profit*, Houghton Mifflin Co.

Luce, R. D. and Raiffa, H. (1957) *Games and Decisions: Introduction and Critical Survey*, John Wiley & Sons.

Mäler, K.-G. (1974) *Environmental Economics: An Theoretical Inquiry*, Johns Hopkins Univ. Press.

Miyamoto, K. (1989) *Environmental Economics*, Iwanami Publishing Co.

Morishima, M. (1999) *Why will Japan Fall?*, Iwanami Publishing Co.

Sakai, Y. (1982) *The Economics of Uncertainty*, Yuhikaku Publishing Co.

Sakai, Y. (1991) *Risk and Information: Towards a New Economics*, Keiso Publishing Co.

Sakai, Y. (2006) *Risk Society:　A Comprehensive Approach*, Iwanami Publishing Co.

Sakai, Y. (2010) *Economic Thought of Risk and Uncertainty*, Minerva Publishing Co.

Sakai, Y. (2011), "Towards 'Symphonic Economic Science'：　My Academic Life and Homage to the late Prof. Michio Morishima," *The Morishima Memorial Lecture*, Shimin University, Kyoto.

Sawa, T. and Ueda, K. , eds. (2002) *Economic Theory of the Environment*, Iwanami Publishing Co.

Schumacher, E. F. (1973) *Small is Beautiful: Economics as if People Mattered*, Blond & Briggs Ltd.

Sinn, H.-W. (1983) *Economic Decisions under Uncertainty*, North-Holland.

Slovic, P. (1987) "Perception of Risk," *Science*, Vol.280.

Taleb, N. N. (2007) *The Black Swan: The Impact of the Highly Improbable*, Random House Publishing Group.

Terada, T. (1934) "Natural Disasters and National Defense," *The Keizai-Ohrai Journal.*

The Presidential/Congressional Commission on Risk Assessment and Risk Management (1997) *Framework for Environmental Health Risk Management, Final Report.*

Uzawa, H. (2003) *Economic Theory and Global Warming*, Cambridge Univ. Press.

World Bank (1997) *Expanding the Measure of Wealth: Indicators of Environmentally Sustainable Development*, World Bank.

Footnotes

1) For environmental economics, see Mäler (1974) and Miyamoto(1980).

2) For a detailed discussion on risk, see Hey (1979), Sakai (1982, 1991, 2006, 2010), and Bernstein (1996).

3) The concept of black swan was first introduced by Taleb (2007).

4) Early systematic discussions on decision making under risk were done by Borch (1968), Hey (1979), Sakai (1982) and Sinn (1983).

5) For the Bernoulli principle and its economic applications, see Arrow (1970) and Diamond & Rothschild (1978).

6) For a detailed analysis, see Sawa & Ueda (2002), Chapter 8. It is in that chapter that I myself developed a new version of the generalized expected utility theory, which is even more general than the prospect theory of Kahneman & Tversky (1979).

7) The introduction of a shift parameter into the utility function is my own idea, which have been rather neglected in the main stream of microeconomics today.

8) As far as my knowledge is concerned, the allocation problem of a thermal power plant was first discussed by myself in 2004, even before the 2011 Great East Japan Earthquake. By writing Chapter 8 in Sawa & Ueda (2008), I intended to break the myth of absolute safety associated with nuclear power generation.

9) In his book (1973), Schumacher discussed whether nuclear energy was really salvation or damnation. Unfortunately, his pioneering work has been more or less ignored in the circle of theoretical economists. I do believe, however, that It should be worthy of more attention, and incorporated into environmental risk management.

10) Investigation into selection of optimal project under true uncertainty remains an underdeveloped area in social sciences. I intend to mend such unfortunate tendency by giving an attempted analysis below.

11) I had a golden opportunity to talk about the life and work of the late Prof. Michio Morishima. See Sakai (2011).