# Economic Valuation of Catastrophe Risks: Beyond Expected Losses Paradigms

Kiyoshi KOBAYASHI*, Muneta YOKOMATSU**

* Department of Civil Engineering, Kyoto University
Yoshida-honmachi, Sakyo-ku, Kyoto, 606-8501, Japan
kkoba@psa2.kuciv.kyoto-u.ac.jp
** Department of Social Systems Engineering, Tottori University
4-101, Koyama-mimami, Tottori, 680-8552, Japan
yoko@sse.tottori-u.ac.jp

Second EuroConference on
GLOBAL CHANGE AND CATASTROPHE RISK MANAGEMENT
Earthquake Risks in Europe
IIASA, A-2361 Laxenburg, Austria
July 6-9, 2000

**Abstract**

The calculation of expected-losses-reduction, adopted in practices of cost-benefit analysis of disaster mitigation investment, fails to capture the catastrophic features of disaster, most typically characterized by large magnitudes of collective damage. The risk management methods to cope with disaster can be classified into two categories: risk control through disaster mitigation and risk financing to allocate catastrophe risks through market transactions. The paper claims that the cost-benefit evaluation of mitigation investment should reflect social applicability of risk financing technology to take into account the catastrophic aspects of natural disaster. The paper presents an extended framework of economic valuation of catastrophe risk mitigation and summarizes remaining issues to be concurred in future research.

## 1 Introduction

Recent advancement of disaster mitigation technologies has remarkably reduced arrivals of damages caused by natural disasters while capital accumulation in urban areas has increased the risks of catastrophic losses whose scales are unprecedented in history. Large scaled disaster seldom occurs, but once it hits a great number of people, firms and organizations are deprived a large amount of wealth simultaneously. This study is concerned with the question of how we can manage such large and collective risks, which may be termed as 'catastrophe risks'.

Traditional cost-benefit analysis evaluates economic benefits of disaster mitigation investment by expected losses reduction. This method, however, is appropriate only for evaluating risks whose scales are relatively small and whose arrivals are mutually independent. In other words, it has the limitations in application and it cannot be adopted to calculation of economic benefits of mitigation investment that aims for reducing catastrophe risks such as earthquakes characterized by large losses and collectiveness. New paradigm is necessary to be introduced, which is consistent with the catastrophic features of disaster risks.

Both means, i.e., 'risk control' such as disaster mitigation and 'risk financing' like disaster insurance should be combined to cope with catastrophic risks. The recent development of financial technologies has expanded the channels of risk spreading, resulting in discounting premium rates and increasing the capacity corresponding to the large claims. It is further expected that popularization of disaster insurance cultivate households' cognizance of disaster risks that they actually face. The effective coordination of technologies of risk control and ones of risk financing is required to construct the disaster risk management systems.

The cost-benefit analysis fills the role of evaluating value of a certain types of risk control technologies by estimating the willingness-to-pay in the prevailing market. Applying the cost-benefit analysis, wasteful investment will be cut in advance. Hence the formulation of cost-benefit analysis must be expanded, and the total risk management system must be constructed, incorporating voluntary prevention of risks by each household and so on, and further the new methodology is expected to help information on disaster risks widely communicated in society. This study suggests the fundamental concepts of cost-benefit analysis in the market where catastrophe risks exist, and points out what is remained for future studies.

# 2 The Economic Evaluation of Catastrophe Risks

## 2.1 Previous Studies

There has been large literature, both theoretical and empirical, about economic valuation under uncertainty[1]. Economic benefits of seismic risk mistigation have been estimatied in Japan[2][3][4]. But most studies implicitly assume that 1) scale of events is small, 2) occurrence of events is mutually independent. They have not focused on the above-mentioned factors, 'low probability' and 'collectivity'. On the contrary, one hit of disaster brings about a large number of victims who are seriously damaged. There have not accumulated the studies about evaluation methods that focused on the peculiarities of disaster risks, which are low probabilities, simultaneous arrivals and serious damage. On the other hand, regarding to collective risks, there are studies where optimal allocation among individuals has been analyzed. The social benefits of avoiding risks have conventionally been defined by summation of individuals' benefits of the avoidance. But the collective feature of catastrophe risks will not accept the conventional method, namely the benefits brought by catastrophe avoidance must not be simple accumulation, without taking the correlation into account, of individuals' benefits of the avoidance. Besides, there exists the study where benefits of avoiding the irreversible catastrophe risks whose hit makes state impossible to be recovered are evaluated [6]. For example, once catastrophic event such as explosions in a nuclear plant occurs, all the households are probable to die. Since deaths of all the households arrive simultaneously, they can be substituted by death of the representative household, and the evaluation of benefits of catastrophe aversion can be replaced to the one of death aversion of the representative household. And here, since the catastrophic event is represented as 'doomsday', there remained no room for discussing about allocation of damage.

## 2.2 Catastrophe Risks

As for disaster risks, both aspects should be considered: collective and individual risks. The former refers to the aggregated amounts of losses suffered by a certain group, while the latter corresponds to actual allocation of the level of losses to each household. Then, disaster risks can be represented by 'compound lottery' that is composed of two stages, which respectively

correspond to determination of collective risks and one of individual risks. At the first stage of the lottery, the number of victims, $N$, (or, equivalently, the total amounts of losses) is drawn from the lottery box. At the second stage, the names of $N$ victims are determined, that is individual risks are discriminatingly allocated among households. This model straightforward points out the essential structure of initial allocation of disaster risks.

By the way, automobile insurance spread individual risks. With regard to the risks like traffic accidents, where damage of contractors are not correlated, individual risks are completely spread in the pool of the premiums paid by the contractors, i.e. traditional mutual insurance. Since total amounts of losses in a certain period can be predicted almost precisely by law of large numbers, collective risk doesn't exist and losses of victims can be always fully covered by accumulated premiums of contractors. Now, suppose the circumstance where three households are homogeneous and they are respectively faced by the risk of losing $3M$ amounts of wealth and the probabilities of the occurrence is $1/3$ a year for each household, accordingly the expected losses for each household is equal to $M$ a year. Hence if insurance premiums are set at the expected losses $M$, $3M$ is gathered in the pool and ready for the event. And now, the risk is traffic accident and the number of victims is exactly 1 every year, therefore $3M$ in the pool compensates completely the losses $3M$ of the damaged household. The reason why the insurance pool functions well that way is that the pool faces no risk every year, it means that there is no collective risk. On the contrary, suppose now that the risk is disaster and the number of victims is stochastic variable; they can be 0, 1 and 2 by probability $1/3$ respectively. This case, the expected amounts of losses of each household are still $M$, and the total expected losses of 3 households are given by $3M$ a year, therefore $3M$ is accumulated in the pool every year. Now the disaster hits 2 households, depriving $6M$ amounts of wealth simultaneously, the pool cannot fully cover their losses. The lack of claims occurs because the pool is as well faced by risks, which we call 'collective risks'. For the former case of traffic risks, the benefits of reducing the risks are calculated by the expected losses reduction, it follows that the individual benefits is identical to the discount of the premiums and the social benefits is equal to the scale-down of the insurance pool. On the other hand, the latter case of disaster risks has additional aspect, collective risks, hence the benefits cannot be evaluated similarly. Then, how?

The question we have to ask first is about spreading the risk of 'lottery of the first stage'. It is apparent that the pool given by households in a region or disaster insurance of the traditional type is insufficient to hedge great collective risks. Insurance money must be raised from international capital markets. The greater the losses, the more money must be made in order to recover the state. Consequently, economic benefits of disaster prevention investment are evaluated by the costs that would be necessitated to hedge the catastrophe risks in the international capital markets if the investment were not implemented.

### 2.3 Risk Financing and Risk Control

There exist a number of technologies applied to the management of disaster risks. These technologies can be roughly classified into the means for risk control and the ones for risk financing. The former corresponds to any means to reduce the magnitudes of losses and damages caused by disasters. The latter refers to institutional arrangement to distribute disaster risks among potential victims. Anti-disaster proof facilities play role of risk control that mitigate either probabilities or losses brought by disaster. As well, emergency systems of refuge and guide, management technologies of traffic, information and communication systems, and methods of restoration works are categorized to risk control methods. On the other hand, disaster insurance is representative technology of risk financing, which state-dependently reallocates the wealth.

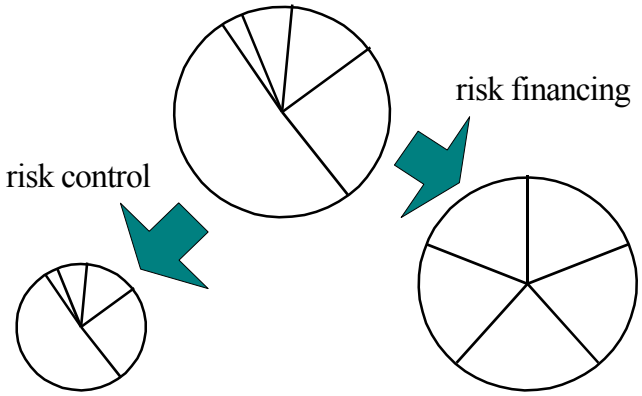


**Figure 1. Risk Control and Risk Financing**

Note that even if damaged households can be compensated by insurance claims, total losses in society brought by disaster are remained to be unchanged. Losses are not disappeared but transferred from victims to undamaged households. The basic differences between the two methods are characterized in **Figure 1**, where the sizes of the circles represent the amount of the total monetary losses caused by certain disaster. Risk-control methods basically orient to mitigate the total monetary losses that could be generated by the disaster, while risk financing methods apply to reduce the damages of the victims by shifting part of the losses of the victims to the undamaged persons, remaining the size of the circle constant. If institutional arrangements of risk financing are insufficiently equipped in society, losses are likely to be concentrated upon a relatively few households and the psychological damage of the victims will be enormous. But if losses are distributed widely, the damage per capita is mitigated. The benefit-evaluation based on expected losses reduction takes only the sizes of the circles in **Figure 1** into account, and neglects the benefits related to the psychological damage of each household.

# 3 Problems in Evaluation of Disaster Risk Mitigation

## 3.1 Limitations of Evaluation Based on Expected Losses Reduction

Traditional cost-benefit analysis evaluates the economic benefits of disaster prevention investment by amounts of expected losses reduction brought by the investment. This method is, however, theoretically justified only if none of the following three conditions is violated; 1) losses of households are fully covered by disaster insurance payments, 2) ex ante states are instantly recovered by the payments (there is no time lag), 3) Principle of Lexis is satisfied, which requires that premium for contractor are equal to his/her respective expected claim payments. The improvement of financial markets has discounted premium to some extent, but insurance industries are still faced with risks and risk premium (safety loading added to expected claim payments) is included in insurance premium unless collective risks are completely diminished. Therefore Principle of Lexis is still far from being satisfied [7]. And since some multiplier, which is greater than 1, marks up pure premium (equal to expected claim payments), households are not motivated to purchase insurance of full cover contract [8]. Unless losses cannot be perfectly compensated by insurance, households cannot wipe off the risks of psychological damage completely. Hence the economic evaluation cannot go ahead without considering how losses by disaster are, actually, initially allocated.

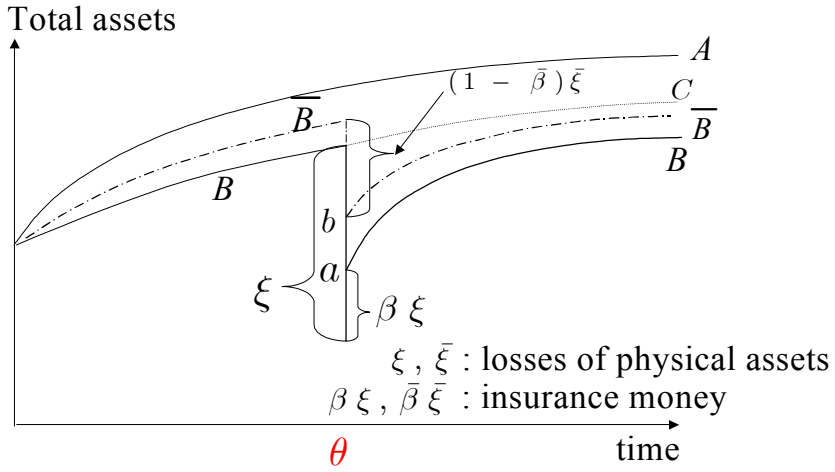


**Figure 2. Capital Accumulation and Disaster Risks**

### 3.2 Psychological Damage and Risk Premium

Let us reveal one of the limitations of the expected-losses-evaluation method. Consider time series where assets of a certain household who do not apart from his/her native land throughout his/her life are accumulated [8]. Suppose that the household makes portfolio composed of monetary assets and physical assets. Monetary assets are assumed to be safe assets that gain constant interest every period. On the other hand, by physical assets, we represent houses and furniture, which are faced with risks of being damaged by disaster. When the household is deprived parts of his/her physical assets by disaster, he/she should adjust his/her portfolio and restart his assets making process. It means that the household is forced to restart his/her remaining life course with lower stocks of assets than his/her ex ante position.

**Figure 2** shows the household's total assets growing process. Assume for simplicity that the household faces no risks other than disaster risks. The path $A$ represents the assets accumulating process in the circumstance where no disaster risk exists. Now, assume the circumstance where physical assets are faced with disaster risks, and the path $B$ represents the process when disaster occurs at time $\theta$ and he/she loses $\xi$ amounts of his/her wealth. Suppose further two market conditions; 1) premium rates are set equal to his/her risks, it follows that it is optimal to purchase full-cover-insurance, and 2) premium rates are marked up, it follows that the household has no incentive to purchase full-cover-insurance and only parts of the losses are compensated at the time of disaster. If insurance market is characterized by 1), the total asset growing process continues after $\theta$, as if nothing happened at $\theta$. Next suppose the case 2) where ex ante position of the wealth is not recovered instantly. The typical process is represented by the path $B'$ (the dashed line), where the insurance money $\beta\xi$ $(1 \geq \beta \geq 0)$ is paid for the losses $\xi$ instantly at time $\theta$. At that moment, the household readjusts the share between monetary assets and physical assets. And after the instant readjustment, the accumulation process of the second period starts from the initial point of $b'$. The second process necessarily goes below the line that would be traced if disaster did not occur. And it means that psychological damage last for long time until the second path converges to the imaginary path. This kind of losses brought by disaster is regarded as 'ex post losses'.

Now, anti-disaster proof facilities are provided, and owing to them, the losses by the disaster at $\theta$ are reduced from $\xi$ to $\bar{\xi}(< \xi)$. This case, the accumulation process traces the path $\bar{B}'$. In other circumstance where losses are fully covered by disaster, direct economic effect is reduction

of disaster insurance premiums. Further if disaster insurance satisfies the Principle of Lexis, the reduction of the premiums is equal to the expected losses reduction, it follows that benefits of disaster prevention investment can be evaluated by present value of expected losses reduction. On the other hand, the path $\bar{B}'$ illustrates the case where losses are not completely compensated by disaster insurance. Now we can resolve the shift from the path $B'$ to $\bar{B}'$ into two effects. The first effect is brought at the time disaster occurs, namely in (ex post) state of disaster, where anti-disaster proof facility mitigates losses actually given by the hit of disaster. It is illustrated by the shift from the point $b'$ to the upper restarting point, which means the initial wealth for the second period increases, and which affects the restarted asset accumulation process. We call this effect 'ex post mitigation effect'. In addition, pay attention to the growing process before $\theta$, where the household has not experienced the disaster yet. The path $\bar{B}'$ is different from the path $B'$ even in this first period. Anti-disaster proof facilities reduce expected losses, and therefore decrease premium rates and insurance premiums, and it follows that those savings of the premiums are substituted for investment to his/her assets. Hence assets growing process is shifted not only at the time of occurrence of disaster but throughout household's life. We call the second effect that is independent of the time of disaster, 'ex ante accumulation effect'.

As has been noted, benefits of disaster prevention investment depend on availability of disaster insurance. Summing up, if disaster insurance satisfies the Principle of Lexis, which means that premiums are equal to the expected claim payments, and household recognize his/her disaster risks completely, then rational household purchase full-cover-insurance. Thus his/her disaster risks are completely hedged by the insurance, and he/she carry out riskless assets making. He/she does not enjoy 'ex post mitigation effect' by anti-disaster proof projects. In other circumstances where losses are only partially insured owing to the market condition, household's assets accumulation process is gifted with risks of being deprived by disaster. Now he/she is given 'ex ante accumulation effect' as well as 'ex post mitigation effect' by the projects.

Whether households make full-cover-contracts or not depends on the existence of risk premiums included in disaster insurance premiums. Let us define risk premium for the time being by the value that is got when premium is divided by expected claim payment. If the Principle of Lexis is satisfied, the risk premium is equal to the minimum value, 1. Yokomatsu *et al.* proved theoretically that if Cobb=Douglas utility function is adopted to represent preference of household, total benefits composed of 'ex ante accumulation effect' and 'ex post mitigation effect' are just equal to the amounts that is got when the amounts of expected losses reduction is multiplied by the risk premium prevailed in the market [8]. This index of the benefits seems simple and useful. However, disaster insurance market, especially we pay attention to one in Japan, has not advanced yet, and we cannot observe correct value of the risk premium that reflects actual disaster risks in respective regions. But in the year 2002, the Japan's financial market is opened, and disaster insurance market is predicted to become competitive rapidly. In result, information about the risk premium will be accumulated and it will be possible to apply the evaluation method based on the market.

### 3.3 Discount Rates for Future Benefits

To measure the dynamic benefits of disaster prevention investment, the discount rate is necessary to evaluate relatively the value of future utility with one of present utility. Now, which value is appropriate for the cost-benefit analysis of this kind of investment? The problem has caused so much controversy that the review of accumulated discussion cannot be covered in this paper. Here, we refer only to a question whether probabilities of occurrence of disaster risks are incorporated into the discount rates or not. The answer is; it depends on the feature

of risks; whether the risks are 'irreversible' or not. Irreversible risks are the risks, after being hit of which ex ante states cannot be recovered again, such like losses of human lives and the doomsday of the world. Yokomatsu *et al.* point out that if targets of projects are irreversible risks, the general discount rates, which is the sum of subjective discount rates of representative household and arrival rates of disaster (irreversible risks), are appropriate for the cost-benefit analysis of disaster prevention investment [10]. And this case, we also evaluate the benefits, which are derived from decreasing of the discount rates. Besides in the study mentioned in the preceding subsection, they introduce the fact that in the circumstance where household can restart his/her life after he/she is deprived his/her wealth by disaster, namely the time series are not terminated by arrival of disaster, just the subjective discount rates of the household must be adopted for the benefits evaluation of risks mitigation[8]. Moreover, even if an object is fatal risk where household cannot recover his/her own life once it occurs, if he/she has pure altruistic preference for his/her descendants, his/her subjective discount rates are appropriate for the cost-benefit analysis, because he/she does not discriminate his/her children's life from his/her own life, that is, the time series do not come to end by his/her death by disaster. Accordingly, future benefits brought by disaster prevention investment are discounted by subjective discount rates as well as general public investment that has nothing to do with risk control. But, for example, in the circumstance where a community is faced by risks of being destroyed by an earthquake, it is justified to adopt the general discount rates that include the arrival rates of the earthquakes.

### 3.4 Sophistication of Cost-Benefit Calculation of Disaster Mitigation Investment

As anti-disaster proof level improve, probabilities of arrivals of events which are characterized by small-scale and large-frequency will decrease, and households' consciousness of disaster prevention will diminish synchronously. However many kinds of anti-disaster proof facilities are insufficiently capable of mitigating probabilities of arrivals of events with large-scale and small-frequency, namely they leak occurrence of catastrophe risks. In order to mitigate catastrophe risks, not only projects implemented by governments but role of financial markets and self-prevention activities of households are required as components of the total disaster management. Accordingly cost-benefit analysis of disaster prevention investment needs to be sophisticated to be consistent with the total risk management system. Damage brought by catastrophe risks, incorporating psychological damage as well, must be more precisely estimated and predicted, and detailed information about disaster risks must be opened to the public. Those activities are mutually promoted with risk communication between governments and regional inhabitants. The benefits evaluation of public investment is not independent of households' private activities for losses mitigation. In subsection **3.2**, the index of the benefits of disaster prevention investment was identified as the product of expected losses reduction and the risk premium of disaster insurance. Note that the model, which derives the index, assumes household's rational behavior regarding to avoiding risks such as purchasing insurance in the market, and further the household is gifted with a sense of self-responsibility. If household violates such normative behaviors based on self-responsibility, his/her willingness-to-pay for anti-disaster facilities provided by government, namely the economic benefits of the facilities, will be much greater than the normative one. But even if such benefits are identified as great amounts, needless to say, it is inefficient to mitigate all the risks by public projects. Policies that introduce households' efforts for private mitigation must be implemented, taking calculation of costs into account. The value of the risk premiums observed in the disaster insurance market gives us valuable

information about possibility of households' private mitigation, indirectly through the amount of expected losses reduction driven by public investment.

# 4 Self-Responsibility-Principle and Market Evaluation of Disaster Mitigation Effects

## 4.1 Technologies of Risk Financing and Disaster Insurance

In 1990's, there increased rapidly the payments of premiums in reinsurance market of disaster insurance. Hurricane Andrew in 1992 and the Northridge earthquake in 1994 particularly motivated this trend. For compensating the parts of the losses brought by the former, $18.3 billions of insurance money were paid (estimated by Swiss Re.), and for the latter, the total payments were achieved $13.5 billions (estimated by Swiss Re.). One of the reasons is that people with high income concentrated in those regions, resulting in increasing the risk of great amounts of insurance payments. Compared with the demand, the scale of the international nonlife insurance markets (including reinsurance markets) is too small to absorb such growing risks. Hence in order to resolve the problem, it was proposed and has been implemented that insurance pool is expanded by transaction of disaster securities (CAT bond) in international capital markets that is incomparably larger than nonlife insurance markets. Disaster risks are uncorrelated to economic risks so that speculators are able to spread risks by composing effective portfolios. This methodology is equivalent to one suggested in the model where collective risks, which is determined in the first stage of 'compound lottery', are hedged by transaction of CAT bond in security market. Kobayashi *et al.* formulate an ideal disaster insurance, which contains the function of CAT bond for making money for payments, supplied in the ideal security market, where Pareto optimal risk allocation is attained. As for this type of the disaster insurance, the risk premium defined in the preceding section is not equal to 1, but more than or less than 1 owing to risks households face respectively. Furthermore, it must be impossible practically to design the disaster insurance system that precisely corresponds to each sample in the sample space of states defined by combinations of individual risks and collective risks. Practical disaster insurance is nothing more than one that roughly corresponds to the samples. Accordingly insurance industries also have to take risks of solvency so that additional safety loading will be far from negligible. A lot of important works are remained for future, for example, CAT bond should be designed more practically and precisely in order to reflect the idiosyncrasies of disaster risks, and moreover, the methodology of determining values of risk premiums should be invented.

## 4.2 Disaster Insurance and Self-Responsibility-Principle

Effects of disaster insurance are not only 1) to fund for damaged households' reconstruction, but 2) to make households have incentive to prevent their own risks as much as possible with sense of self-responsibility. For example, suppose that premium rates are so designed as to decrease inverse-proportionally to the degree of anti-disaster proof level of private building that is an object of insurance. Now households will have incentive to strengthen structures of buildings in order to save payments for the insurance premiums. As is mentioned above, theoretically, disaster insurance can induce households' private preventing behaviors, and popularization of disaster insurance and enhancement of households' consciousness of risk management and activation of their private mitigation complementarily make progress. However, seeing the present market condition in Japan, disaster insurance is far from being popularized. Even in the United

States, which is regarded as advanced country of disaster insurance, it is reported that the level of households' cognition of risks is insufficient[11]. The reasons why insurance is not purchased are presumed as follows; first, information about disaster risks is not supplied to the public. Recently hazard maps are depicted and help the information communicate to the public, but they are, in fact, not detailed information and even the existence of the map is not the common knowledge in society. The second is that households are likely to lack incentive to purchase insurance voluntarily in market when they expect some relief programs for actual victims of disasters implemented by governments. Those kinds of imperfect cognition[12], moral hazard, and existence of transaction costs distort market allocation of risks, resulting in market failure. On the other hand, policies of governments that enforce compulsory insurance as institution can be suggested. For example, regional governments, which are expected to hold more precise information about risks of respective regions than households and act better against risks with less moral hazard, can levy the taxes from respective inhabitants as insurance premium, and buy the disaster insurance in the market to insure the losses of the inhabitants[13]. In some circumstances, mixed insurance system, where compulsory insurance and market insurance are combined, may be valuable[14]. However those compulsory systems can, as well, be objected with a foundation that unlike the automobile insurance which aims at protecting the injured, disaster insurance is nothing more than one which compensates the wealth of the owners themselves, and the compulsion may violates the property right. Hence advanced studies must be accumulated, which examine more desirable institution of disaster insurance from many aspects, resolving households' imperfect cognition of risks and moral hazard.

### 4.3 Risk Communication

As anti-disaster proof level in a region improves, inhabitants come to less sensitive against danger of disaster. Protection against disaster cannot be obtained without payment. Households, by facing the concrete decision problem of purchasing disaster insurance in market and being given premium rates as prices of the insurance, will recognize their respective risks. As has been described in the preceding subsection, compulsion of insurance is not necessary the desirable method, and it must rather be regarded as the second best policy because of several negative factors. On the other hand, governments must make efforts such like PR activities for prevalence of disaster insurance to enhance households' cognition level of risks. Thus the economic effects of anti-disaster proof projects will become possible to be evaluated in the market by reduction of the premium rates. In addition, the risk information will be communicated to households by the prices. The degree of prevalence of disaster insurance can be regarded as some index that tells us the degree of households' cognition of risks. All in all, disaster insurance market is the place where risk communication realizes, so that institutional arrangements for the market to function well must be provided further. One of the most important arrangements is that rankings of the risks of respective lands are required for the pricing of the insurance in the market. Professional organizations should take the roles of the ranking and those organizations must be cultivated and some international qualifications need to be given to sophisticated technologies for the evaluation of disaster risks. In the year 2002, insurance market is opened in Japan as is called like 'Financial Big Ban'. Hence provisions of the institutional arrangements are required in a hurry. At present point of time, one of the feasible methods will be to oblige households to notify the results of investigation of the proof levels of the buildings when they are constructed or reconstructed or transacted as used condition. Even if respective households are gifted with the rights of decision not to purchase disaster insurance in market, it might be valuable to institutionalize the procedures of confirming their wills.

### 4.4 Efficient Allocation and Fair Allocation of Risks

Most important future direction of the cost-benefit analysis based on the disaster insurance market will be to include the problem of fair allocation of risks among individuals. Kobayashi *et al.* prove that the equilibrium solution in the market, where the disaster insurance is transacted, surely attains Pareto efficient allocation of catastrophe risks, on the other hand, larger amounts of wealth are allocated to the households whose expected marginal utility is smaller (who own larger amounts of wealth)[7]. Namely, we gain more inverse allocation of wealth than one which is given if we adopt the social welfare function where households' expected utility functions are simply added. In other words, the buyers of the disaster insurance are wealthy households, and relatively poor households have less incentive to buy the insurance. For the purpose of equitable allocation, some policies by governments are required, and again, compulsory insurance system might be investigated although it is equipped above-mentioned problems.

## 5 Concluding Remarks

Economic benefits of disaster prevention investment have conventionally been evaluated by expected losses reduction. Once disaster hits, a great number of people, firms and organizations are deprived a large amount of wealth simultaneously. The traditional method based on expected losses reduction is faced by the limitation that it cannot be applied to the market of catastrophe risks where securities that are not satisfy the Principle of Lexis are transacted. This study referred to the categorization of technologies of risk management into risk control such like anti-disaster proof facilities and risk financing such like disaster insurance. In order to manage growing risks in society, the total risk management system must be constructed, where methods of risk control and ones of risk financing are effectively and consistently combined. In addition, the frame of the cost-benefit analysis must be sophisticated. This paper discussed about the possibilities of extension of framework of economic valuation of catastrophe risks mitigation, and it could make clear about remaining issues to be concurred in future research.

## References


[1] Johansson, P.-O.:'Cost-Benefit Analysis of Environmental Change', *Cambridge University Press*, 1993.

[2] Ueda, T.:'On the Benefit of Natural Disaster Prevention Project from the Points of Uncertainty and Economic Disequlibrium',*Proceedings of Infrastructure Planning*, No.14, pp.17-34, 1997 (in Japanese).

[3] Tatano, H.:'Project Evaluation under Uncertainty : Issues and Perspective',*Proceedings of Infrastructure Planning*, No.20(2), pp.19-30, 1997 (in Japanese).

[4] Takagi, Y., Morisugi, H. Ueda, T., *et al.* : 'The Benefit Evaluation of The Flood Control Works with Location Equilibrium Model',*Proceedings of Infrastructure Planning*, No.13, pp.339-348, 1996 (in Japanese).

[5] Starrett, D. A:'On the social risk premium, in: Heller, W. P., Starr, R. M., and Starrett, D.A.(eds.)' *Social Choice and Public Decision Making: Essays in Honor of Kenneth J. Arrow*, Vol. 1, pp.159-176, Cambridge University Press, 1986.

[6] Johansson P.-O. and Löfgren, K.-G.:'Wealth from optimal health', *Journal of Health Economics*, Vol. 14, pp.65-79, 1995.

[7] Kobayashi, K., Yokomatsu, M. : 'Catastrophe Risks and Economic Valuation of Disaster Prevention Investment', *Journal of Infrastructure Planning and Management,* No. 639/IV-46, pp. 39-52, 2000(in Japanese).

[8] Yokomatsu, M., Kobayashi, K. : 'Economic Benefit of Physical Risk Reduction by Disaster Prevention Investment'*Journal of Infrastructure Planning and Management*,to appear, (in Japanese).

[9] Stiglitz, J. E.: 'Economics of the Public Sector', W. W. Norton, 1986.

[10] Yokomatsu, M., Kobayashi, K. : 'The Economic Benefits of Irreversible Risk Reduction by Disaster Prevention Investment', *Proceedings of Infrastructure Planning,* No.16, pp.393-402, 1999(in Japanese).

[11] Froot, K. A. (ed.):'The Financing of Catastrophe Risk',*The University of Chicago Press*, 1999.

[12] Kunreuther, H. *et al.*:'Disaster Insurance Protection: Public Policy Lessons',*John Wiley*, 1978.

[13] Yokomatsu, M., Kobayashi, K. : 'The Optimal Regional Allocation of Disaster Risk by Jurisdiction-Managed Insurance', *Proceedings of Infrastructure Planning,* to appear, (in Japanese).

[14] Blomqvist, Å. and Johansson, P.-O.: 'Economic efficiency and mixed public/private insurance', *Journal of Public economics*, Vol. 66, pp. 505-516, 1997.