ECONOMIC MEASURE OF COST-BENEFIT ANALYSIS UNDER DISASTER RISK AND MITIGATION POLICY

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***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 finance to allocate catastrophe risks through market transactions. The paper claims that the cost-benefit evaluation of mitigation investment should reflect social applicability of risk finance 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.

KEYWORDS: Management of disaster damage, Management of economic and social influence

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 adapted 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 finance' 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 finance 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 (e.g. Johansson, 1993). Economic benefits of seismic risk mistigation have been estimatied in Japan (e.g. Ueda, 1997, Takagi et al.,1996). 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 (Johansson, 1995). 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 spreads 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, and losses of victims can be always fully covered by accumulated premiums of contractors. On the contrary, as for disaster risk, the number of victims is stochastic variable, 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 are identical to the discount of the premiums and the social benefits are 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 control and risk finance

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 finance. The former

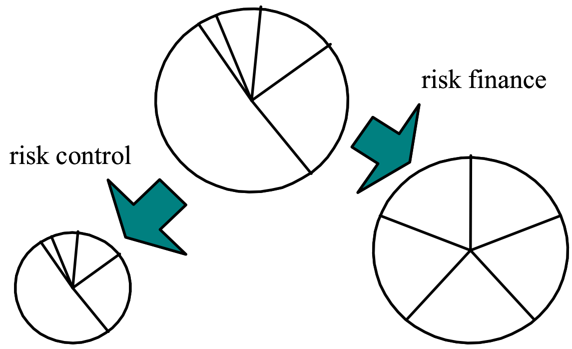

Figure 1. Risk control and risk finance

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 finance, which state-dependently reallocates the wealth. 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 finance 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 finance 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 its 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 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 (Kobayashi et al., 2000). Unless losses cannot be perfectly compensated by insurance, households cannot wipe off the mental damage that comes from uncertain future completely. Hence the economic evaluation cannot go ahead

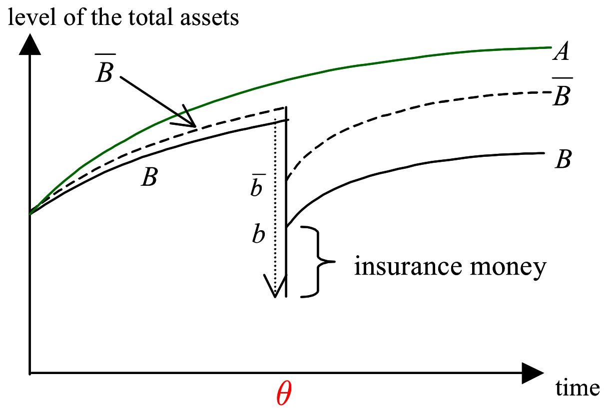

Figure 2. Capital accumulation and disaster risk

without considering how losses by disaster are actually and initially allocated.

3.2 Mental 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 its native land throughout its life are accumulated (Yokomatsu et al., 2000a). 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.

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 θ. Now, since insurance premium rates are marked up, the rational household has no incentive to purchase full-cover-insurance and only parts of the losses are compensated at the time of disaster. Hence ex ante position of the wealth is not recovered instantly. The typical process is represented by the path *B*, where at time θ the household readjusts the share between monetary assets and physical assets, and the accumulation process of the second period starts. The second process necessarily goes below the path *A*, that is, mental damage lasts 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. Owing to them, the losses by the disaster at θ are mitigated and the accumulation path is shifted up to the path $\overline{B}$. The shift is resolved into two effects. The first effect is brought at θ, 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 $\overline{b}$, which affects the restarted asset accumulation process. We call this effect `ex post mitigation effect'. On the other hand, the path $\overline{B}$ 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 its 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'.

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. (2000a) 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. 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 was opened, and disaster insurance market is now 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 Sophistication of cost-benefit calculation of disaster mitigation investment

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 mental 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, its 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 finance 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 are 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.(2000) formulates 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 insolvency 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, risk communication, 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. The reasons why insurance is not purchased are considered in several ways, such as lack of risk information, moral hazard and so on. The moral hazard in this context means 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, 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 (Yokomatsu et al., 2000b). In some circumstances, mixed insurance system, where compulsory insurance and market insurance are combined, may be valuable (see e.g. Blomqvist et al., 1997). 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. Moreover compulsory systems may deprive households of opportunities where they recognize their respective risks by insurance premium, namely, opportunities of risk communication in market. 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 Efficient allocation and fair allocation of risks

One of most important future directions 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. (2000) proved 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). Namely, we gain more regressive 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 of 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 do 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 finance 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 finance are effectively and consistently combined. In addition, the frame of the cost-benefit analysis must be sophisticated. This paper insisted that cost-benefit analysis based on self-responsibility-principle should take risk premium into account. Future study examines how our conclusion is consistent with hypothetical compensation principles and compensation tests, considering the possibility of governments' intergenerational risk sharing policy.

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