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## Flood Insurance as a Flood Management Tool: An Economic Perspective

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Flood Insurance as a Flood  
Management Tool:  
An Economic Perspective

Tun Lin, Franklin D. De Guzman,  
and Maria Cita Cuevas

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# FLOOD INSURANCE AS A FLOOD MANAGEMENT TOOL: AN ECONOMIC PERSPECTIVE

TUN LIN, FRANKLIN D. DE GUZMAN, AND MARIA CITA CUEVAS

AUGUST 2007

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## **FOREWORD**

The ERD Working Paper Series is a forum for ongoing and recently completed research and policy studies undertaken in the Asian Development Bank or on its behalf. The Series is a quick-disseminating, informal publication meant to stimulate discussion and elicit feedback. Papers published under this Series could subsequently be revised for publication as articles in professional journals or chapters in books.



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## **ABSTRACT**

Flood insurance is an insurance contract that covers losses to properties caused by flooding. Although floods affect Asia more than any other continent in the world, flood insurance is still at its nascent stage in the region. This paper explores the potentials and challenges of adapting flood insurance to the Asian setting. Due to the need to explore alternative flood management schemes and the context-specificity of flooding, country-specific design and testing of a feasible flood insurance is deemed necessary. This paper presents key aspects of flood insurance including economic design issues.



## I. INTRODUCTION

Perennial flooding<sup>1</sup> has resulted in human casualties, damage to properties, and disruption of economic activities in the affected areas. Floods exacerbate poverty since the impact of flooding falls disproportionately on the poor. Countries have adopted both structural and nonstructural measures as flood management tools to address flooding and its associated risks. Structural measures include engineering interventions, such as construction of dams or dikes,<sup>2</sup> river levees, and embankments; river diversion; widening and deepening of river beds; and setting up of flood detention basins. On the other hand, nonstructural measures consist of flood insurance, flood forecasting and warning systems, restriction development planning, water proofing, and other nonengineering actions.

Flood insurance is an insurance contract sold to individuals whose properties are exposed to flood risk. It seeks to compensate for losses caused by flooding. In developing countries, a typical flood management scheme focuses mostly on structural measures. Flood insurance, in particular, is practically nonexistent. One province in the People's Republic of China (PRC) piloted a flood insurance scheme in the 1980s. The program was suspended 3 years after it was introduced, and since then, no progress has been made on flood insurance in the country.

Traditional responses to flooding problems (flood prevention, disaster relief, and reconstruction) in Asia have been constrained by the governments' generally weak fiscal position. This necessitates examination of alternative flood management tools that allow cost sharing between the government and the communities at risk to flooding. This paper seeks to assess the potentials of flood insurance. It focuses on exploring the possibilities of adapting a flood insurance scheme that suits country-specific conditions, given various informational limitations. The paper puts forward a theoretical model showing that a policy, which places a user-charge to both existing residents and migrants, would result in a smaller population and dike size in the floodplain. Consequently, the potential economic losses and government spending for flood management decreases. Three key messages emerge from the discussions. First, a carefully designed flood insurance scheme may have the potential to counter the adverse incentives created by structural measures for flood management. It can provide the mechanism for transferring benefits from nonaffected persons to affected individuals. Second, a few economic issues and challenges need to be carefully considered in the design and adoption of flood insurance. Third, given the need to explore alternative responses to flooding, the Asian Development Bank (ADB) can play a role beyond what it has enunciated in its water policy, *Water for All* (ADB 2003). Relevant and value-adding country-specific advisory assistance would be needed for designing and testing a feasible flood insurance scheme.

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<sup>1</sup> There is no clear-cut definition of flooding. The Center for Research on the Epidemiology of Disasters (CRED) defines flood as any significant rise of water level in a stream, lake, reservoir or coastal region. Other terms such as river flooding, dike failure, storm surge, flash flood, tsunami, or ice jam are closely related to flooding.

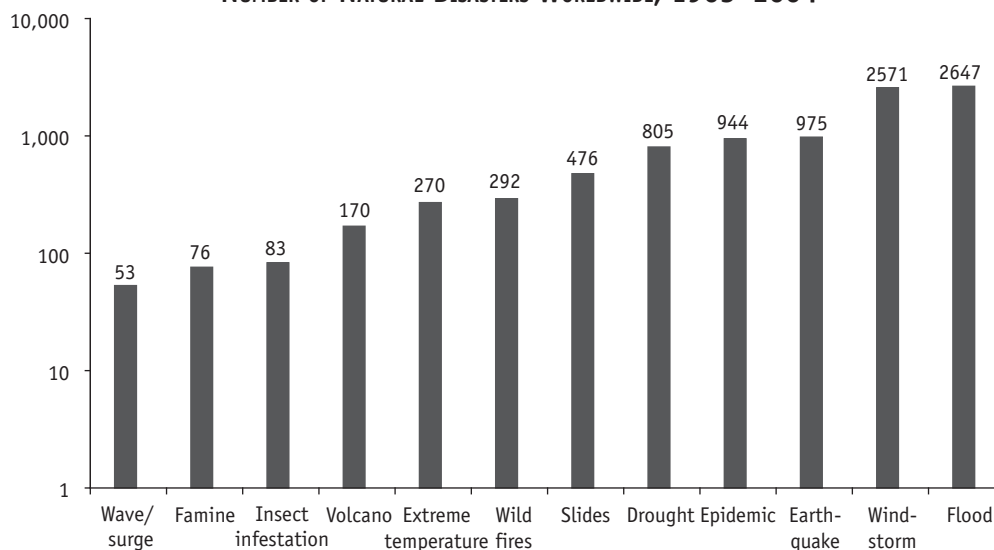
<sup>2</sup> Dams and dikes are used interchangeably throughout this paper.

The paper is organized as follows. Section II provides an overview of flood damage worldwide, specifically the Asian region. Section III examines both structural and nonstructural measures for flood management using perspectives relating to financial and distributional considerations, risk mitigation, and population change and land use. A human behavior model is drawn up, which provides that people decide to settle in a particular area based on the cost of living in that area. Section IV describes the challenges (including some country experiences) and economic issues in designing and implementing flood insurance. Section V outlines operational implications for ADB and Section VI draws some conclusions.

## II. OVERVIEW OF FLOOD DAMAGE

Floods are the most frequent and devastating of natural disasters that have occurred worldwide during the past century. The number of reported natural disasters in the world reached 9,632 during the period 1905–2004,<sup>3</sup> with floods accounting for about 28% of the total (Figure 1). Damage to infrastructure, crops, housing, etc. have been placed at hundreds of billions of dollars, accounting for about 40% of the economic damage brought about by all types of natural disasters. Millions of lives are lost in the process. The last century's floods killed nearly the same number of people as all other natural disasters combined. As business operations are disrupted and decreased earnings are translated into lower tax revenue collections, social programs also suffer because tax money spent on relief and recovery efforts crowd out expenditures intended for health and education. Flood disasters also indirectly cause transportation delays, spread of diseases, power outages, and water contamination (ADRC 2002 and Myers 1997).

FIGURE 1  
NUMBER OF NATURAL DISASTERS WORLDWIDE, 1905–2004



Source: CRED (2006).

<sup>3</sup> Datasets used in this review are from CRED (2006), which were compiled from various sources including the United Nations, government and nongovernment agencies, insurance companies, research institutes, and press agencies. Disasters included in the CRED database complied with at least one of the following criteria: (i) 10 or more people reported killed; (ii) 100 [or more] people reported to be affected; (iii) state of emergency declared in the area; and (iv) disaster entailed a call for international assistance.

Floods affect Asia more than any other continent. Asia experienced a total of 1,229 flood disasters, or 41% of the world total during the last 100 years (Table 1). Statistics for 2000–2004 showed that the frequency of floods in Asia increased rapidly, with an annual average of 58 flood disasters. South Asia is the most affected region in Asia (and globally) with a reported incidence of 427 flood disasters. India is the most affected country in Asia, followed closely by the People’s Republic of China (PRC).<sup>4</sup> The increasing trend of flood disasters in Asia has been accompanied by mass devastation in human lives (Table 1). During the 100-year period, the PRC alone reported 6.6 million deaths and US\$118 billion worth of damage. The PRC’s average loss from floods was RMB110 billion each year since 1990, which is equivalent to 1% of the country’s gross domestic product (GDP). However, the extent of devastation may not be proportional to the frequency of flood disasters. For instance, Viet Nam has less than half the number of floods than Indonesia, but the cost of its damage is greater than that of Indonesia.

**TABLE 1**  
**HUMAN CASUALTIES AND COST OF FLOOD DAMAGE WORLDWIDE, 1900–2006**

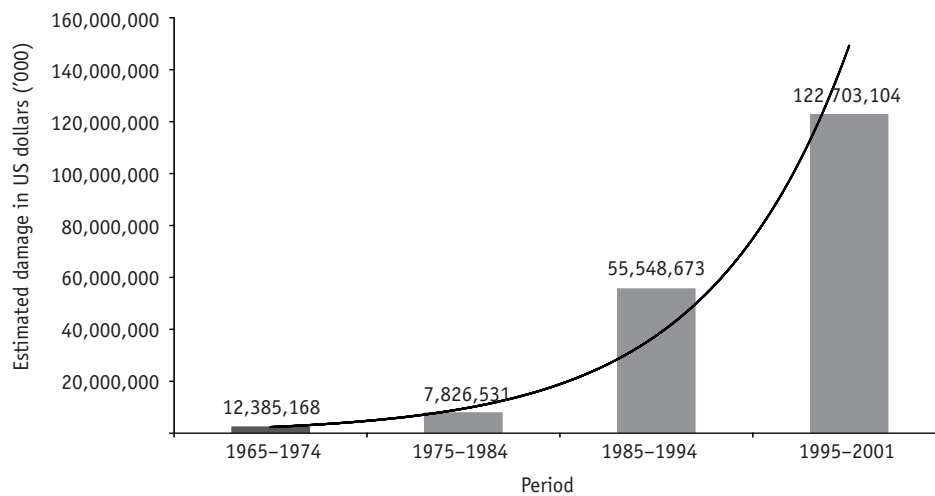
	NUMBER OF EVENTS	KILLED	INJURED	HOMELESS	AFFECTED	TOTAL AFFECTED	DAMAGE (US\$ '000)
<b>Asia</b>	1,229	6,765,544	1,199,680	99,497,893	2,695,378,959	2,796,076,532	205,047,004
Average per event		5,505	976	80,958	2,193,148	2,275,083	166,841
<b>Americas</b>	749	100,768	41,805	3,316,543	49,934,423	53,292,771	61,539,314
Average per event		135	56	4,428	66,668	71,152	82,162
<b>Africa</b>	526	20,186	22,636	4,665,522	35,134,801	39,822,959	3,941,585
Average per event		38	43	8,870	66,796	75,709	7,494
<b>Europe</b>	422	9,244	21,775	1,969,976	12,615,623	14,607,374	80,805,760
Average per event		22	52	4,668	29,895	34,615	191,483
<b>Oceania</b>	99	370	91	107,400	465,785	573,276	2,384,911
Average per event		4	1	1,085	4,705	5,791	24,090

Source: CRED database.

Figure 2 shows the economic losses in Asia caused by floods since 1965. Economic losses have gone up exponentially over the past four decades. The loss during 1995–2004 was more than 60 times higher than the loss during 1965–1974. The case of the PRC partly explains this, wherein the arable lands affected and destroyed by floods almost doubled in the 1990s compared to the 1950s, despite having constructed 277,000 kilometers of river dikes and 85,000 reservoirs (Yong 2005). Houses destroyed by floods also increased from 2.3 million in the 1950s to 2.7 million in the 1990s.

<sup>4</sup> Completing the top ten are Indonesia, Bangladesh, Philippines, Iran, Thailand, Pakistan, Japan, and Viet Nam, respectively.

FIGURE 2  
ECONOMIC LOSSES DUE TO FLOOD DISASTERS, 1965–2004



Source: CRED (2006).

### III. FLOOD MANAGEMENT: STRUCTURAL AND NONSTRUCTURAL MEASURES

Structural measures or engineering interventions are designed to keep floodwaters away from people. Technically speaking, there is no flood risk that cannot be mitigated by structural or engineering measures, however, the cost may be prohibitive.<sup>5</sup> On the other hand, nonstructural measures aim to keep people away from floodwaters or to teach them to live rationally amid the threats of flooding through prudent land management and disaster preparedness. If structural measures are the bones of a flood management program, nonstructural mitigation is considered as its flesh (UNESCO 2001). As will be shown in the succeeding sections, major differences between structural and nonstructural measures can be highlighted by looking at the financial and distributional considerations, their risk mitigation effectiveness, and impacts on population growth and land use.

#### A. Flood Management Measures in Asia

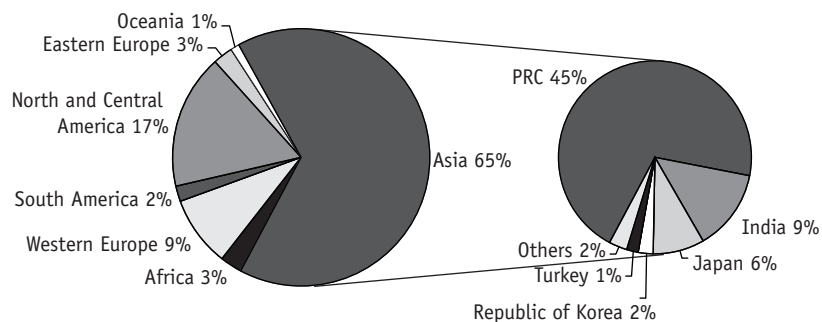
In Asia, structural measures remain as the focus of flood prevention. Investing on preventive or engineering measures is perceived to be cheaper and more effective in the long term due to the large number of people affected by flooding. Globally, Asia is the most prolific in terms of the number of dams in operation and under construction, having about 65% of the world's dam total.<sup>6</sup> Around 80% of Asian reservoirs have volumes greater than 100 million cubic meters. Also, about 40% of dams in Asia are higher than 30 meters. Both percentages are above the world average (Figure 3).

<sup>5</sup> Worldwide investments in dam constructions reached \$2 trillion during the last century, with an average rate of one large dam being built per day (World Commission on Dams 2000). Over 80% of large dams in the world were built after the 1950s. Dams are constructed for many purposes including irrigation, hydropower, water supply, flood management, etc. Flood management dams are also used for power generation and irrigation because they are usually needed for only a few days or weeks in a particular year.

<sup>6</sup> People's Republic of China, India, Japan, Republic of Korea, and Turkey are among the most active dam-building countries.

The PRC has flood-prone areas that are inhabited by more than 66% of its total population. These areas produce two thirds of the country's total agriculture and industrial production. The PRC currently has 45% of the world's dams and still has very active construction programs. India is the most flood-affected country in the world in terms of number of disasters and flood-prone areas, which are estimated at 40 million hectares or 12% of the country's total geographical area. Dams in India account for 9% of the total number of dams in the world. In the case of Japan, 50% of its population live in flood-prone areas, and floods have affected 80% of its municipalities in the 1990s. Japan has thus become one of the top five dam-building countries in the world and accounts for about 6% of the world's total.

**FIGURE 3**  
**GLOBAL DISTRIBUTION OF DAMS, 2000**



Source: World Commission on Dams (2000).

## B. Financial Considerations

Implementation of flood management measures contributes to a government's fiscal burden. With the increasing frequency of flood disasters, the cost of disaster prevention, relief, and reconstruction, including the consequent economic losses of flooding have grown concomitantly. In the United States (US), the federal government spent \$38 billion on flood management, mostly on structural measures, between 1960 and 1985. Yet, average annual flood damage, adjusted for inflation, continued to increase, and in fact, more than doubled from the previous period investigated (Schildgen 1999).<sup>7</sup> In the PRC, the China Ministry of Finance and World Bank (WB) statistics showed an 18.2% average annual growth rate of government relief funds for natural disaster from 1962 to 2003, as compared to an average growth rate of 6.9% in the country's GDP during the same period. Worldwide, disaster relief expense climbs up when flood damage increases at a rate faster than government revenues do.<sup>8</sup>

Construction of dams is not only financially prohibitive. It is also subject to significant uncertainties, such as geotechnical conditions at the site and quality of the construction materials,

<sup>7</sup> Inflation-adjusted average of flood damage was estimated at \$1.7 billion during 1903–1933, \$2.7 billion during 1934–1963, \$4.6 billion in 1964–1993, and \$5.1 billion during the period 1994–1997.

<sup>8</sup> Comparing two 13-year periods (1980–1992 and 1993–2005), the government revenue income for G-7 countries increased 89% on average, but the recorded average economic losses due to floods went up by more than 50 times. All seven countries have significantly higher growth in flood losses than in government revenues.

which often cannot be determined precisely until construction is under way. The World Commission on Dams (WCD) estimates that worldwide, more than half (54%) of dams have incurred cost overruns (2000). Moreover, increased sedimentation and the continuous growth in population and the local economy have made it imperative to invest in additional structural measures, such as raising the height of dikes. This increase in fiscal burden has become the foremost incentive for governments to consider nonstructural measures, such as flood insurance, which entails a cost-sharing arrangement among property and business owners, insurance and re-insurance industry, and government.

Box 1 discusses the nexus of dams, insurance, and population growth from a budgetary perspective. Over time, these factors contribute to the decrease in the dams' effectiveness, resulting in another round of dam construction or raising of the dike height.<sup>9</sup>

**Box 1**  
**DAMS, INSURANCE, AND POPULATION GROWTH: A BUDGETARY PERSPECTIVE**

Flood insurance and engineering measures have different effects on population growth in flood-prone areas. Structural flood protection measures lower the costs of living and investments in the flood-prone areas, and therefore tend to increase the population and economic activities in these areas. As population increases and economic growth occur, potential flood damage also increases, necessitating further engineering interventions. Flood insurance can work the opposite way by adding (part of) the insurance premium back to the individuals' calculation of costs of living and investments.

Let us assume the government has a fixed budget for flood disaster relief and will undertake mitigation measures when the aggregated expected loss (AEL) exceeds this budget. The AEL depends on the population living in the floodplain. The population changes when the cost of living in the floodplain also changes. If the floodplain population exceeds the critical level, the AEL would be greater than the governmental relief budget, and therefore certain flood mitigation measures would be required. In such a case, two mitigation options may be considered: building a dam (or improving existing structures) or initiating flood insurance. Building a dam lowers the flood hazard probability, and hence, lowers the AEL. Alternatively, flood insurance acts as a mechanism for the government and the private sector to share the expected deficit in flood disaster relief and reconstruction. Building a dam is cheaper on a per capita basis, i.e., the greater the number of people in the floodplain, the lesser the cost of construction per individual. However, this only holds true in the short term. In the long run, dam construction encourages the population to grow while flood insurance possibly discourages it. The more people move into and reside in the floodplain, the higher the need for mitigating flood risk and the greater the potential economic losses become.

Although no formal economic model is found, Figure 4 suffices in demonstrating the idea. In the figure, the horizontal axis is the number of people living in the flood-prone area, denoted by  $n$ , which can be broadly interpreted as any asset under the threat of flood. For ease of illustration, we assume it as the number of people at a point in time. The vertical axis is the AEL, which is a function of both the number of potential victims and the disaster probability. Clearly, AEL increases with  $n$ , which is represented by an upward curve in the figure, as well as disaster probability. Government, as the disaster relief agent, faces a budget constraint represented by a horizontal line. Box Figure 1 shows that there is a critical level of population  $n^*$ , below which the AEL is within the government budget line. This means that with existing flood prevention measures, the government expects, ex ante, to be able to provide disaster relief.

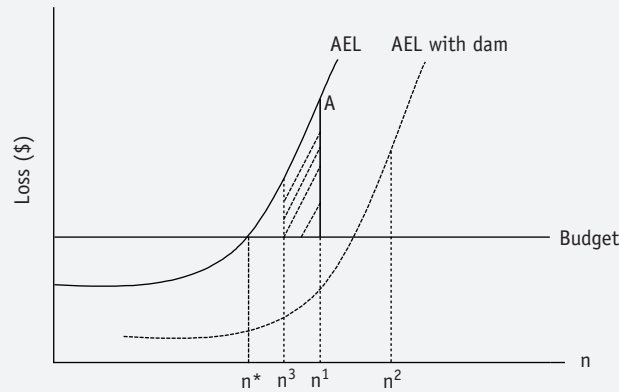
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<sup>9</sup> For centuries, dikes in Viet Nam have been progressively increased in height as the river bed has gradually risen due to accumulating sediments deposited by floods. The same situation prevails in the PRC, where the height of dikes on the Yangtze River has gone beyond 16 meters above the floodplain.



Box 1. *continued.*

**BOX FIGURE 1**  
**INTERACTION BETWEEN FLOOD MANAGEMENT POLICIES**  
**AND POPULATION CHANGE: AN ILLUSTRATION**



AEL means aggregated expected loss.

However, if the population exceeds the critical level  $n^*$  to  $n^1$  level, the government, expecting insufficient money to provide the disaster relief, needs to take some actions. One option is to construct a dam. This would decrease the probability of flooding. After the dam has been constructed, flooding would become less probable. With the same population size, the expected disaster relief would be lesser. This is shown by a shift of AEL curve toward a southeast direction in the figure (the dotted curve). Now with population  $n^1$ , the AEL is within the budget.

There is a potential serious problem with this option if one takes into account population increase as a result of building of the dam. Dam construction decreases the probability of floods, and consequently the cost of living in the flood-prone area. This would encourage migration and business development in the area, and probably even higher fertility rate. Population growth depends on the specification and assumptions of the model. For the moment, let us assume that the population increases from  $n^1$  to  $n^2$ . What follows is that the AEL exceeds the budget again. This situation would necessitate more dam construction (new or improvements).

One of the alternative options is flood insurance. Instead of working on the flood probability as what structural measures do, flood insurance establishes a public-private partnership for sharing the disaster cost. When the population is  $n^1$ , the government can initiate such a program to share the part of AEL that exceeds the budget line (line AB in the figure). This option becomes more attractive when people's location or fertility decision is taken into account. Instead of encouraging inward migration and higher fertility rate, flood insurance can have the opposite effect because the insurance premium increases the cost of living in the area. For illustration purposes, let us assume that with the implementation of flood insurance, the population decreases from  $n^1$  to  $n^3$ . The shaded area in the figure represents the public fund saved.

### C. Distributional Considerations

An upstream dike can benefit communities located very far at the downstream. However, not everyone equally shares the benefits of enhanced safety. Also, in rare cases where a dike breaks during heavy storms, populations downstream may be subjected to extreme flooding. Dacy and Kunreuther (1969) criticize the inefficiency of society in bearing the cost of flood protection in the form of structural flood management measures where benefits accrue to only a few individuals. A study on dams' distribution of irrigation benefits in India concluded that there was a failure of state-level redistributive institutions. Dams increase rural poverty in districts where they are located, while poverty declines in districts downstream from the dam (Duflo and Pande 2006).

Adverse environmental and health consequences of structural measures are also borne unevenly by the affected population. Large dams, for example, generate opposition in most cases due to the perceived associated social and environmental costs. To date, an estimated 40–80 million people have been involuntarily resettled, mostly through forced eviction, in favor of dam constructions. Prevention of floods by dams has entailed higher cost to farmers, fisherfolk, and those dependent on floodplain resources (International Rivers Network 2000). In addition, large dams contribute to climate change because they release 104 million metric tons of methane each year (Lima et al. 2007). Health problems also ensue since reservoirs often provide habitat for vector breeding, causing diseases such as malaria and filariasis (Sharma 2006).

Identification of beneficiaries of flood management measures is difficult. And even when the beneficiaries are identifiable, there is rarely any effective redistributive mechanism that allows for beneficiaries to compensate the population who suffers from the dam construction. Whenever a disaster occurs, the government often has to decide on whether to allow flooding of certain places in order to protect other areas. This practice is compounded by the absence of an effective mechanism that allows residents of protected or beneficiary areas to pay for damage in the flood detention areas, except for some implicit and indirect transfers between the beneficiaries and the victims that are managed by the government. In a federal government system, it is extremely difficult to make an intermediate "sacrifice-A-to-save-B" decision before or during the disaster, and arrange compensatory transfers from B to A after the disaster. A flood insurance scheme has the potential to establish an automatic mechanism that enables beneficiaries to pay flood victims, if both are covered by the same insurance program or provider. Premiums paid by beneficiaries will form part of the benefit claims filed by the flood victims.

### D. Risk Mitigation

Both structural and nonstructural measures entail expending scarce public resources. The formula below can help determine which of them is more effective in risk mitigation:

$$\text{Risk} = \text{Hazard Probability} \times \text{Vulnerability} \times \text{Exposure}$$

where hazard probability is the likelihood of flood, vulnerability is the likelihood of damage to properties and other infrastructure, and exposure is the economic and social impact of flooding.

A simple way to determine cost effectiveness of different flood management measures is to compare their respective unit cost impacts on the risk. For example, there are two options proposed for flood management in region X: an embankment that costs Y; and a community-based flood-warning system (e.g., observation points and warning bells), which costs Z. First, evaluate

the risk impacts of both options. In the case of embankment, in addition to reduction in hazard probability, possible increases in vulnerability and exposure to floods due to property development and increase in population in the affected area also need to be taken into consideration. Next, the risk impacts of each option must be weighed against the cost. The preferred option should be the one with higher risk mitigation impact per unit cost.

Dams reduce the hazard probability by managing the peak flows and reducing the probability of water breaching which endanger lives and properties. However, risk impacts of dams are rarely studied and quantified (even more rarely for nonstructural measures), as pointed out by an ADB study (2002). Countries that have constructed more dams do not necessarily have fewer flood disasters and economic losses. Data from 132 countries on the number of dams and the flood disasters after the 1960s was examined. Countries were categorized by the number of dams into six groups: 1–4 dams, 5–9 dams, 10–49 dams, 50–99 dams, 100–499 dams, and more than 500 dams. Compared to within-the-group variation, very minimal across-group variation was found in the growth rate of flood disasters during the period. On average the incidence of flood disasters has not decreased in countries that have more dams during the periods investigated. In fact, the reverse argument—that countries having more dams also have higher growth rate of disasters—is supported by some subsample data. Among 23 OECD countries,<sup>10</sup> 10 countries have more than 500 dams. However, the number of reported flood disasters in these 10 countries, on average, increased by 232% from the period 1980–1993 to 1994–2006, as compared to 43% in the other 13 countries. The difference is statistically significant at 5% level.<sup>11</sup> Given this, if structural measures would encourage population, property, or business development in the flood-prone areas, vulnerability and exposure might increase.

## E. Population Change and Land Use

Three factors explain the close correlation between the structural measures for flood mitigation and the economic losses due to flood disasters, as discussed previously in Box 1. First, economic growth enables more construction works, but at the same time, it makes flood disasters more costly. Dams or dikes, for example, draw more people and encourage business development in the floodplain due to the perceived sense of security from flood disasters. Through time, this development and population growth justify further increase in the size and scale of dams or dikes. Second, high economic losses due to floods, or expectation of further losses in the future, encourage construction of more dams and dikes. Third, the reverse causality is also possible, which points to dike construction as a contributing factor to the increasing economic losses. More dams and dikes could unwittingly encourage economic and population growth in the floodplain, which may lead to greater economic losses in the event of flooding.<sup>12</sup>

These arguments that support the close correlation between structural measures and economic losses provide some caution on the sustainability of using dikes or dams to mitigate flood risks without considering possible changes in population and land uses. In many countries rapid population growth is the primary reason for the continued reclamation and resettlement along the main rivers. Inappropriate land use in these areas significantly reduces the storage and detention capacities

<sup>10</sup> Flood data for Czech Republic, Denmark, Finland, Greece, Hungary, Norway, and Slovakia were not included because they are either missing or incomplete.

<sup>11</sup> One limitation of the data is that only a small fraction of the dams were constructed solely for flood mitigation purposes.

<sup>12</sup> For example, after the Mississippi flood in 1993, a US congressional testimony pointed out that dams and levees exacerbate the flooding problem (Schildgen 1999).

of the river basins, thereby increasing flood flows along the channels. Lands intended for flood regulation are being used for agriculture and human settlement purposes. Structural measures can also raise river beds, which create additional risks for the inhabitants.

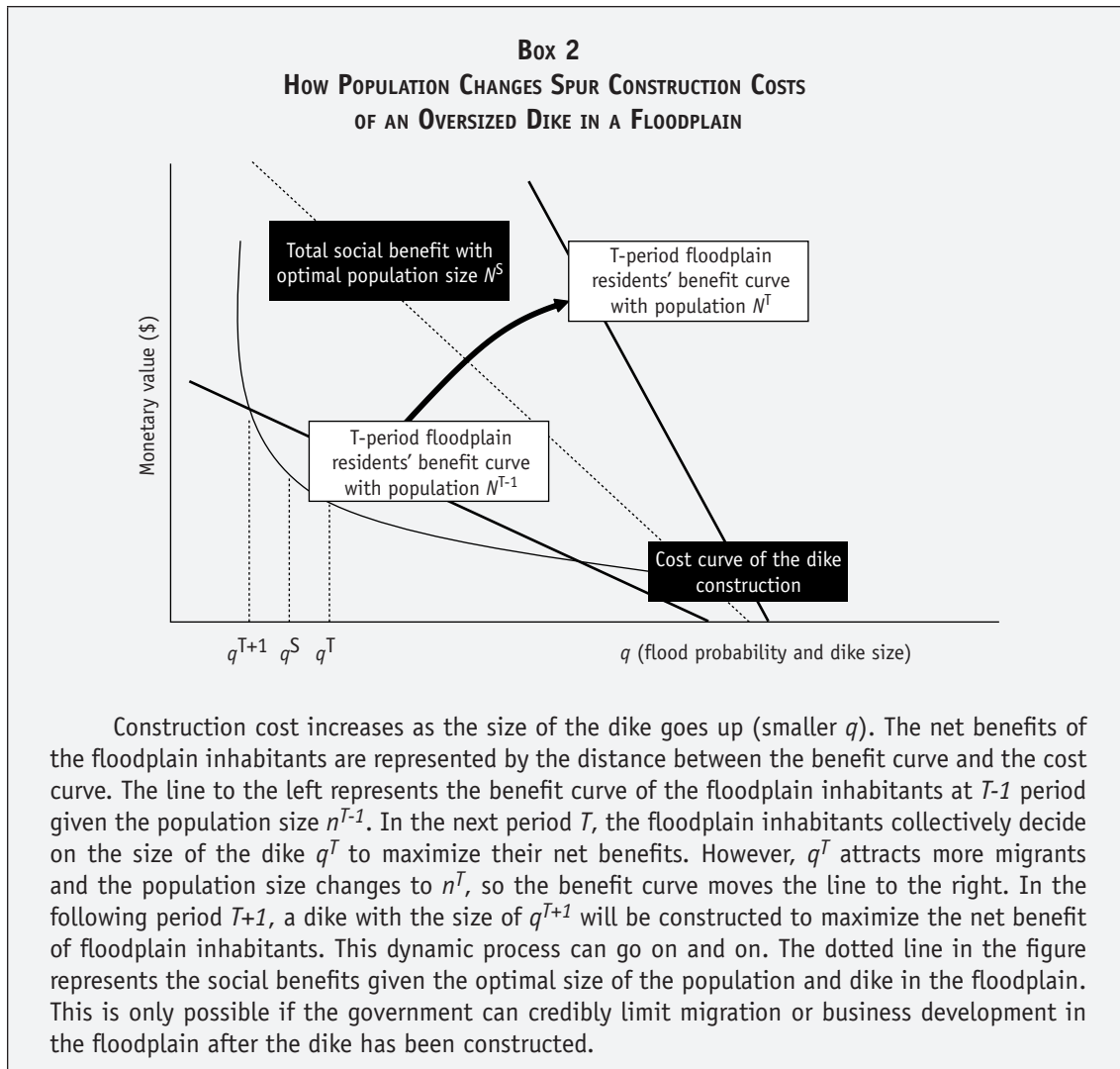
Conventional wisdom argues that there is nothing wrong for individuals to “free ride” in the positive externalities provided by structural measures. Increases in congestion and property prices in the floodplain will eventually be curbed by market forces. This paper argues differently. Individuals incur “moving costs”—broadly defined to include cost of transportation, settling in the new place, and finding a job—when they resettle in a floodplain. Migrants factor in moving costs when they compare the difference in expected incomes in and out of the flood-prone area. If migrants are allowed to free ride the additional security brought about by structural measures while having the existing residents of the floodplain pay for it, moving costs would not deter migration, even by those living further from the floodplain, because part of the moving costs, would be offset by the “free” additional safety. A model in Appendix A shows that people make decisions to settle in a particular area based on the cost of living.<sup>13</sup>

Conventional wisdom likewise suggests that the positive externalities of public goods lead to undersupply of the goods. This paper shows otherwise, that is, the public good nature of the dike leads to the oversupply of the dike over time. Without considering the effects on future migration into the floodplain, larger dikes are constructed. As more people move into the floodplain and the local economy grows, the fear of incurring larger economic losses from flooding justifies an even bigger or higher dike. Such a vicious circle is illustrated in Box 2.

Nonstructural measures provide different locative incentives for changing population and land uses. Flood insurance, for instance, could either increase or decrease the costs of living and investments in the flood prone areas, depending on the policy design and the expectations of the people prior to the introduction of flood insurance. The effects on the cost of living also depend on whether the flood insurance substitutes for the public guarantee provided by the government. If the policy and people’s expectation are for the government to shoulder the cost of disaster prevention and disaster relief, the introduction of flood insurance can increase the costs of living and investments by substituting the public guarantee with private insurance. However, if the policy and people’s expectation is that the communities and individuals are going to bear the consequences of a flood disaster without much help from the government, introduction of flood insurance might decrease the cost of living and investments by pooling the risks of communities and providing a less costly option for risk mitigation. Evatt (2000) reviews 32 studies of the National Flood Insurance Program (NFIP) in the US and concludes that there is insufficient empirical evidence to support the view that NFIP spurs floodplain growth. A mandatory flood insurance, depending on its design, has the potential to offset the impacts of structural flood protection measures on increased population and economic activities in the flood-prone areas by adding part of the insurance premium back to people’s calculation of costs of living and investments.

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<sup>13</sup> To illustrate our idea in the sharpest possible way, we ignore all the technical complications of dam construction and assume a simple relationship between the construction cost and the reduced probability of the flood disaster, i.e., the higher the cost is, the bigger/higher the dam becomes. This lessens the probability of flooding.



#### IV. FLOOD INSURANCE AS A NONSTRUCTURAL MEASURE: CHALLENGES

Flood insurance has been recognized in recent years as a complementary tool in the overall flood management scheme. As an insurance contract sold to individuals whose properties are exposed to flood risks, flood insurance is designed to compensate losses caused by flooding. It has been argued that the best time to consider flood insurance is when appropriate structural and other nonstructural measures are already in place (Andjelkovic 2001). The potential advantages are mainly two-fold. First, flood insurance can help ease a government's fiscal burden for disaster prevention and relief by involving individuals and private insurance providers. It also allows for a more automated transfer of payments from the nonaffected persons to flood victims who are covered by the same insurance program. Second, flood insurance also has the potential to influence an individual's locative decision, which can counter the adverse incentives created by structural measures for people to

migrate into or establish businesses in flood-prone areas. The succeeding paragraphs discuss the challenges to flood insurance, some country experiences, and economic issues pertaining to flood insurance. A framework of analysis for adopting flood insurance is also presented.

### A. Potential Challenges

The viability of an insurance scheme centers on cost. Methods of offsetting risk involve some cost in the form of insurance premiums or foregone income opportunities. When individuals attempt to obtain insurance, they implicitly calculate whether the likelihood and scale of an event would be serious enough to justify the cost of the insurance. Similarly, an insurer is also faced with the difficulty of calculating the attendant costs of providing insurance. It has to assess the likelihood and cost of damage against the premiums set at a rate that the market will bear. The insurer also takes into consideration a government's response to the calamity. A government or international community's action that readily comes in to cover the costs of a catastrophe reduces the attractiveness of insurance (DFID 2004).

There are serious challenges—i.e., supply, demand, and government and market factors—for flood insurance to function well. On the supply side, insurers may find it hard to design insurance products because of the difficulties in assessing flood risk and people's vulnerability, including estimating the potential damage of the flood. Also, high administrative costs in certain areas (especially rural areas), lack of access to reinsurance markets, and global climate change that causes extreme weather disturbances tend to adversely affect the commercial viability of these products. On the demand side, low demand for flood insurance, especially voluntary insurance, has been observed around the world. This is a result of a combination of lack of information, limited risk collective (the people who pool the risks), comprehensive government rescue or expectation of it, and low income. On the market and government side, relevant legislations and policies, as well as partnership schemes in flood management between the government and the private sector, have yet to be established in most developing countries. Table 2 summarizes these potential challenges. Some of the supply side and demand side factors are elaborated in the succeeding paragraphs.

**TABLE 2**  
**POTENTIAL CHALLENGES IN ADOPTING FLOOD INSURANCE FOR DEVELOPING COUNTRIES**

Supply Side Factors	<ul style="list-style-type: none"> <li>• Difficulty in assessing risk and vulnerability before the disaster</li> <li>• Difficulty in estimating damage after the disaster</li> <li>• High administrative costs</li> <li>• Limited access to reinsurance markets</li> <li>• Global climate change</li> </ul>
Demand Side Factors	<ul style="list-style-type: none"> <li>• High premium due to limited risk collective</li> <li>• Limited awareness and information</li> <li>• Moral hazard problem (relying on government's disaster relief)</li> <li>• Low income</li> </ul>
Market and Government Factors	<ul style="list-style-type: none"> <li>• Lack of relevant legislations and policies</li> <li>• Lack of clear partnership scheme between the government and the private sector</li> </ul>

## 1. Supply Side Factors

- (i) *Assessing risk and vulnerability presents a big challenge for insurers.* Demand for flood insurance is higher in areas that are repeatedly affected by floods and are clearly at risk. When insurers have difficulty assessing the risk of flood disaster for a particular area, it is only rational for them to assume high disaster risk and charge high premiums. High premiums, in return, dampen the demand for insurance from medium or low-risk groups of people. This results in a typical adverse selection or anti-selection problem.

Anti-selection problem is universal to almost all insurance products where there is information asymmetry between the insurers and the insured. For some reasons, flood insurance promotes adverse selection. First, at the community level, many developing countries with no flood insurance do not have flood maps that are based on hydro-meteorological information. Without flood maps, insurers would find it extremely difficult to assess the flood risk of a property. As such, events that would trigger indemnity become hard to define. Second, at the individual property level, there is usually a lack of information on flood-proofing features of properties, which prevent an accurate assessment of risk. The last source of information deficiencies comes from the unobservable characteristics at the individual person level, such as the caution and effort put in to prevent the disaster and to save the property during the disaster. Theoretically, the unobservable individual characteristics are the main factors driving the anti-selection problem. However, the first two factors at the community level and the property level tend to present bigger constraints to the development of flood insurance in Asia.

- (ii) *Estimating flood damage can be difficult for insurers.* Apart from the difficulty of assessing flood risk, damage assessment presents another challenge. Flood insurance contracts are usually designed in such a way that flood victims are paid out according to their losses, subject to a certain cap. If the losses are self-reported, there are incentives for the policyholders to provide insurers with wrong or misleading information regarding the damage, and expect transfers commensurate to their claims. Verifying damage could present huge informational constraints to the insurers. The NFIP estimates flood losses based on a hypothetical acre composed of the proportion of each land use. Lacewell and Eidman (1972) criticize the procedure of developing inequitable land owner assessments and propose a more general model for estimating flood losses and insurance premiums based on a point sample. Moreover, in pooling together flooding risks across villages of different river basins, flood insurance, by design, has to cover large anonymous groups and spatial distance, which further complicates the job of verifying losses and damage.

A recent development in the financial market, including the catastrophe bonds or cat bonds and weather derivatives, points to a possible new direction of



basing the compensation on more measurable and objective indices, such as rainfall or river flow velocity. This is a promising area for further study. Box 3 introduces the concept of flood-derived contracts that stipulate how payment will be exchanged between the parties, depending on certain meteorological conditions during the contract period. This can be a useful instrument to modify or supplement conventional flood insurance contracts.

### Box 3 FLOOD DERIVATIVE CONTRACTS

For conventional flood insurance, defining “floods”, assessing their risks, and verifying the losses they entail present serious challenges. An alternative form of flood insurance contract is flood derivative, which may be able to address these challenges. Flood derivative is a concept borrowed from the increasingly popular markets of weather derivatives. The concept is introduced here, and it is up to the readers to decide on its desirability and feasibility as a flood risk mitigation instrument or as a supplementary instrument to conventional flood insurance for people whose properties need additional coverage.

A flood derivative is a contract between two parties that stipulates how payment will be exchanged between the parties depending on certain meteorological conditions during the contract period. A generic flood derivative contract can be formed by specifying the following parameters:

1. Contract type (call, put, or swap)
2. Contract period
3. An official weather station from which the meteorological record is obtained
4. Definition of flood index ( $F$ ) underlying the contract
5. Strike ( $S$ )
6. Tick ( $k$ ) or constant payment ( $P_0$ ) for a linear or binary payment scheme
7. Premium payment ( $P$ )

The parameters above determine the amount of payment ( $P$ ) that the seller is obliged to make to the buyer. For a linear payment scheme,

$$P_{\text{put}} = k \cdot \max(S - F, 0) \text{ and } P_{\text{call}} = k \cdot \max(F - S, 0)$$

For a binary payment scheme,

$$P_{\text{put}} = P_0 \text{ if } F - S < 0; P_{\text{put}} = 0 \text{ if } F - S \geq 0; \text{ and} \\ P_{\text{call}} = P_0 \text{ if } F - S > 0; P_{\text{call}} = 0 \text{ if } F - S \leq 0.$$

For example, the government is selling a call contract at price  $P_{\text{call}}$ , which entitles each contract holder  $P_0$  if the peak river flow ( $F$ ) observed in certain station is greater than a strike level ( $S$ ) during certain period (contract period). The introduction of purchases of such contracts provides a certain degree of assurance to people, whose properties are exposed to flood risks, i.e., if floods destroy their properties, they will be able to get some money back from their call contract.

A flood derivative can be a useful instrument for mitigating flood risks. The type and level of protection will be decided by each individual buyer—subject to their incomes, risk attitude, and the extent of flooding that would affect their properties and livelihoods. There are two premises for such a system to work: (i) a trustworthy flood index  $F$  including its probabilistic state, and (ii) the fair price established through careful studies. It is possible that there will only be a limited number of suppliers and consumers of these contracts because local market is unlikely to be liquid enough. The traditional flood relief provided by the government can be viewed as a special form of flood derivative contract with price equal to zero or some implicit taxes.



(iii) *Limited access to reinsurance market and global climate change tends to increase the cost of providing flood insurance.* In developing countries formal weather-related insurance markets are generally weak. The limited access to insurance markets tends to increase the cost of providing flood insurance and leads governments to attempt to meet disaster costs through tax revenues or borrowing. At the same time, global climate change that induces flooding can also increase the insurance cost (DFID 2004). For example, during the 1997–1998 El Nino phenomenon, which is the strongest episode of drought in history, costly floods occurred more frequently than normal in the southern part of the US. Concerns related to climate change have been shared by an increasing number of insurers since the past three to four decades witnessed significant increases in global flooding.

## 2. Demand Side Factors

- (i) *Limited risk-sharing pool dampens demand for flood insurance.* Insurers usually charge premiums that are commensurate with the flood risk and administrative costs, unless competition forces them to cross-subsidize flood insurance with other insurance products. There are two important consequences of offering flood insurance to a limited population on risk sharing pool. First, mutual insurance characteristics are lost. Insurance mechanism works better when potential risks are spread across a bigger population. This explains why existing flood insurance programs tend to have national-level coverage. Second, if the loss burden is distributed over a small population, the premiums become considerably more expensive. Thus, limited risk collective results in each individual paying a high premium. Both consequences, in turn, dampen the demand for flood insurance.
- (ii) *Flood insurance will not improve economic efficiency, if people do not fully understand the risks involved in building or purchasing properties in flood-prone areas.* Krutilla (1966) noted that a compulsory national flood insurance program could greatly improve the economic efficiency of floodplain occupancy in the US. However, in order to realize the efficiency gains suggested by Krutilla and by the arguments in the previous sections of this paper, property owners must have sufficient information about flood risk and insurance premiums in order to make well-informed home purchase decisions. Chivers and Flores (2002) used survey data to show that there is a general market failure on information majority of the floodplain residents do not fully understand the degree of flood risk or the cost of insuring against this risk when negotiating the purchase of their properties.
- (iii) *Individuals at risk may not be prepared to pay premiums for flood insurance due to moral hazard problem.* People will have a higher tendency to stay in flood-prone areas when they know that they will be bailed out in case of a disaster. Thus, they have less incentive to purchase flood insurance for self-protection. If individuals at risk expect the state to compensate their loss through disaster relief, the moral hazard problem discourages them from

exercising due caution and avoiding unnecessary risks. This is actually very common in many developing countries in which people build their dwellings in flood-prone areas and expect the government to provide flood protection and disaster relief.

- (iv) *The poor usually have a greater need for flood insurance, but cannot afford it without substantial government subsidy.* Almost all flood-prone areas in Asia are in the developing countries, except Japan. However, the overall low income level presents a serious affordability constraint in promoting flood insurance. Paradoxically, within the floodplain, poorer households need flood insurance the most. Poor households are usually more vulnerable to floods than the rich. Poor households have insufficient resources to invest in flood-proofing measures for their houses and have fewer choices in diversifying the risk (e.g., by dispersing household members geographically). In addition, the poor generally have less access to savings and credit facilities needed to cope with difficulties in the aftermath of a disaster. The big challenge is how flood insurance can be designed in such a way that will make premiums affordable to poor households.

## **B. Some Country Experiences**

Experience of some countries that have attempted to initiate flood insurance programs provide valuable lessons. The following briefly indicates country experiences in five countries: Australia, PRC, France, United Kingdom, and United States.<sup>14</sup>

### **1. United States: Government as a Provider of Subsidized Flood Insurance**

Eight out of the ten costly disasters in US history were caused by hurricanes that resulted in widespread flooding. It is estimated that flooding causes more than \$2 billion in property damage yearly. The federal government-run NFIP was initiated as a response to private market's failure to provide adequate flood insurance. On the supply side, American insurance industry is well developed and capable of assessing risks and estimating damage. Flood maps have been developed throughout the country by the government. However, the cost of providing flood insurance still remains high, which has been highlighted especially after the onslaught of Hurricane Katrina. On the demand side, property owners are not inclined to purchase flood insurance unless damage is expected in the near future. In this context, the federal government acts both as a relief agency and a provider of subsidized flood insurance.

These twin functions hinder the development of privately provided flood insurance. Assured financial assistance from the federal government in the event of flooding has made property owners less inclined to invest in flood insurance. Also, the subsidized actuarial rates effectively discourage provision of market-based flood insurance. Under this level of involvement, the federal government has also to contend with attendant issues, such as the need to reduce the fiscal burden resulting from sustained flooding losses and the implicit subsidy on high-risk properties that encourages property development in hazardous areas.

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<sup>14</sup> More information on the experience of each country is available from the authors upon request.

Key experiences and elements of flood insurance in the US include the following: (i) insurance coverage is reserved for communities that have undertaken floodplain management programs (including construction licensing, implementation of flood proofing, introduction of laws prohibiting buildings in floodways, etc.); (ii) premium rates are determined to provide incentives for appropriate levels and types of development in floodplains; (iii) subsidy of premiums is only provided for house insurance; and (iv) participation of all affected persons and entities is compulsory.

## **2. United Kingdom: Informal Partnership between Government and Insurance Companies**

In the United Kingdom (UK), an estimated 1.8 million homes and 130,000 commercial properties are at risk from both inland and coastal flooding. The British insurance industry is well developed in providing insurance products. An informal partnership has evolved between the insurance industry and the government that is based on division of responsibilities. Initially, insurance companies had to provide relatively cheap flood insurance regardless of the risk level under this institutional arrangement. The government, for its part, had to undertake adequate flood defenses and control over developments in flood hazard areas.

Heavy flooding in 2000 triggered a reassessment of this institutional arrangement, especially on the insurability of flood losses and the role of government in flood management. Climatic changes, aging flood protection structures, and property developments in flood-prone areas were considered as contributing factors to the widespread flooding. It was argued that greater frequency of such flooding occurrences could pose serious implications on the solvency of the insurance industry. Another issue was the failure to reflect in the premiums the increased cost of insurance coverage. In 2002 amendments to the informal partnership were made, which include reforms in the areas of land use planning, administrative reforms in flood protection, increased budgetary outlay for flood protection, and modification of land use regulations. For the insurance industry, the main focus of reform was on insurability. Now insurability is conditional and premiums are differentiated according to levels of risks and exposure.

## **3. France: Government Imposes Mandatory Insurance, Decides the Level of Extra Charge, and Declares State of Natural Catastrophe that Triggers Compensation**

The French parliament enacted a law in 1982 establishing the Catastrophes Naturelles (CatNat) insurance system for natural disasters as a response to several incidents of heavy flooding. This system is mandatory and covers “uninsurable” events such as earthquake, flood, drought, avalanche, tidal wave, and landslide. The scheme provides increased insurance to cover economic losses from these uninsurable disasters. When a state of natural catastrophe is declared, local communities and the private sector can apply for damage compensation. The level of the extra charge is decided by the government and is uniformly applied to all private insurance contracts. Losses are distributed between both the calamity victims and those that are not affected by the event. Insurance companies protect themselves from insolvency under this plan by purchasing reinsurance. However, this reinsurance scheme is optional and can be purchased in the private market or from the government-owned reinsurer. It is argued that the compulsory nature of CatNat, given the standard premium rates, provides no incentive for the policyholder to reduce the level of risk.

A parallel indemnification system called “storm guaranty” also exists, which covers insurable natural events such as windstorm, ice, and snow. Under this scheme, storms are not considered as catastrophe. Hence, such occurrence is covered exclusively by private insurance. However, if a storm results in flooding, CatNat and storm guaranty can operate at the same time to allocate claims.

#### **4. Australia: Hands-off Policy Does not Work too Well**

In Australia floods have accounted for 29% of the total cost of natural disaster over the past 30 years. The government provides assistance in disaster management, including disaster mitigation and relief. However, it has adopted a hands-off policy on flood insurance provision. Generally, insurance cover is not readily available, although some insurance protection is provided by private insurance companies to residential properties for damage due to storm and flash flooding. Comprehensive flood insurance is deemed not financially feasible because of weak demand. This is further aggravated by some definitional problems on what constitutes floods, which affect actuarial calculations including assessments of causes, costs, and damage and risks to be covered. Insufficiency of reliable flood risk data has also been cited as a major contributing factor to the limited availability of flood insurance products.

Other issues are still considered unresolved. These include (i) adverse selection problem; (ii) affordability of premiums, particularly in high-risk areas; (iii) perception that insurance may discourage flood damage reduction activities; (iv) uneven distribution of risk and claims that can affect most policyholders at the same time; and (v) nonimposition of tax on the reserves held by insurance companies.

#### **5. People’s Republic of China: Pilot Program Failed due to Inadequate Understanding of the Nature of Flood Risk both by the Government and the General Public**

In 1984 a pilot project of flood insurance in a flood diversion passage area of Ying Shang County, Anhui Province, was initiated by Huaihe River Basin Commission, Provincial Bureau of Water Resources, Provincial Insurance Company, and other concerned agencies. On average, flooding in the area occurs once every 10 years during summer, and once every 3 years during autumn. The premium was based on flood frequency and on the economic losses of crops, which vary by season. Some 30% of the premium was paid by the peasants, while the government subsidized the remaining 70 percent. Agriculture was exempted from tax. The policy required certain level of maintenance of the levee of the flood diversion passage so that floodwaters could pass through. The project was suspended when no flood took place 3 years after the project was initiated. The people and the local government decided to withdraw the premium, which totalled RMB4.8 million. Unfortunately, the area was heavily damaged by a 1991 flood when compensation was no longer available.

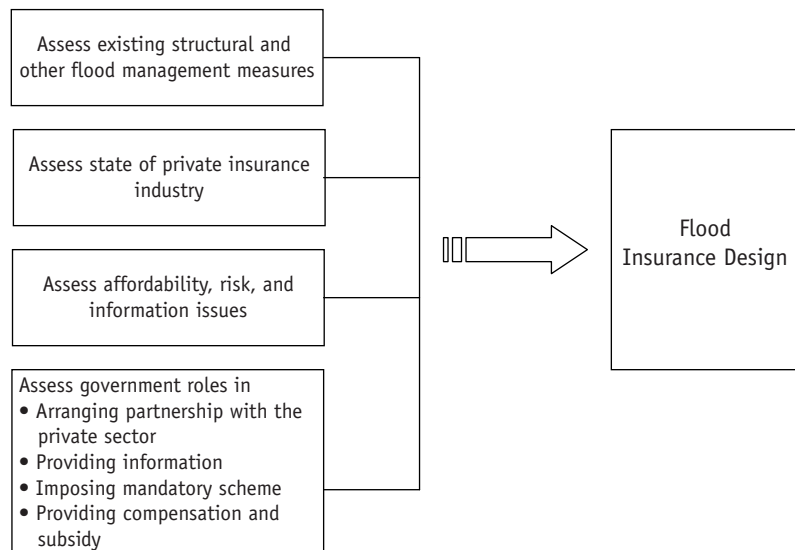
Since then, flood insurance has made little progress in the PRC, mainly for the following reasons. First, the levee systems in flood-prone areas are very weak, and these pose high risk of payment on the part of the insurance company in case of damage to the levee system. Second, it is difficult to formulate clear guidelines for identifying flood risks in flood-prone areas. This, in turn, makes it difficult to establish an appropriate premium for flood insurance. Unlike the natural river system, floodplains are protected by flood-control civil works. Thus, the risks depend on many factors and, to some extent, are uncertain. Third, residents in flood-prone areas are relatively poor and are

reluctant to pay insurance premiums. This reluctance is reinforced by the traditional perception that relief from the government will always be available when a flood disaster occurs.

## V. ECONOMIC ISSUES IN THE DESIGN OF FLOOD INSURANCE

Relevant design issues pertain to the extent to which flood insurance features can be formulated in ways that are compatible to the country setting. This paper proposes a framework of analysis to better assess the applicability of a flood insurance scheme and help minimize practical difficulties in its implementation. Figure 5 suggests analytical considerations in developing an affordable and an efficient flood insurance scheme.

**FIGURE 5**  
**ANALYTICAL FRAMEWORK IN ADOPTING FLOOD INSURANCE**



### A. Assess Existing Structural and Other Flood Management Measures

The effectiveness and desirability of existing structural and other flood management measures provide an important context for determining the potential for and appropriate design of a flood insurance scheme. Governments usually finance engineering solutions such as the construction and restoration of flood defenses.

Following the analysis in Section III, four aspects of structural flood management measures need to be carefully reviewed. The first has to do with fiscal impacts. Current and planned structural measures need to be assessed in terms of their soundness and the government's capability to shoulder construction, operation, and maintenance costs. Analyzing the fiscal impact of flood mitigation measures, therefore, involves assessing the past, current, and projected levels of government expenditures in flood defenses. In some cases, a precondition for the provision of flood insurance by the insurance industry depends on the government's commitment to provide effective flood defenses. In the UK, budgetary allocations and investments were deemed to be significantly below

the levels necessary to meet the standards of service of the Department of Environment, Flood and Rural Affairs. These largely contributed to the decision in 2002 of the private insurance industry to impose a moratorium in flood insurance. Stronger commitment by the state in the area of prevention was viewed as a means of deterring the higher frequency of flooding, which could pose serious implications on the solvency of the insurance industry.

The second aspect is distributional—how different people have been or will be affected by the structural flood management measures and whether there is a need for a transfer mechanism from the beneficiaries to the flood victims.

The last two aspects have to do with the overall risk mitigation, and population and land use changes. The overall risk level is not only affected by the reduction in hazard probability, but also by the people's vulnerability and their exposure to risk. In order to assess potential population, property and business development induced by the structural measures in the flood-prone areas, the tariff settings of such structural measures have to be reviewed carefully along with the population and property growth data in the area.

## **B. Assess State of Private Insurance Industry**

On the supply side, an assessment should be made on the current state of the insurance industry to determine the provision and coverage of flood insurance products. In developing countries, most private insurance companies do not provide flood insurance. In cases where flood insurance is offered, extent of coverage needs to be reviewed. In Australia, insurance cover for other forms of flood damage does not appear to be readily available, although some insurance protection is provided for damage to residential properties from storm and flash flooding. Only a few specialized insurers offer limited cover. In cases where insurance cover is available, it is often considered only as a supplement and is subsumed or hidden in the policy for special industrial risks. Hence, the analysis should assess the extent to which viable flood insurance products are being offered in the market.

If there is indeed an underprovision of flood insurance by private insurers, the reasons need to be carefully examined. The insurance industry will only provide a universal coverage if flood insurance venture is profitable. Given the catastrophic nature of floods, flood risks could be very high if there are insufficient flood protection structural measures and huge population density in the flood-prone areas. These residents would have frequent or repeated claims, hence the cost of supplying or providing flood insurance could be prohibitively high. The cost could also be high due to private insurance industry's limited capacity, low operational efficiency, insufficient risk information, and limited access to reinsurance markets. Factors contributing to the lack of private flood insurance need to be carefully assessed not only for the cost estimates of supplying flood insurance by the private sector in a sustainable and profitable way, but also for ways of improving private insurance sector efficiency and lowering the cost of supply of flood insurance.

## **C. Assess People's Capacity and Willingness to Pay, and Attitudes Toward and Knowledge of Flood Risk**

Ideally, the private insurance industry should provide full access to flood insurance by the vast majority of the target population at affordable rates. As such, it is important to study potential flood victims' capacity and willingness-to-pay, including attitudes toward and knowledge of flood



risk. An individual's willingness to pay for flood insurance is affected by factors such as income, risk awareness, and expectation of flood relief. Insufficient demand for flood disaster insurance can be attributed to low income levels of potential flood victims. When certain individuals cannot afford the insurance, cost may have to be subsidized by the government, or collectively, by communities. Alternatively, as the PRC experience shows, an insurance scheme may have to be complemented by other low-risk sharing mechanisms in poorer communities, such as kinship networks, microfinance, and public works programs to increase coping capacities (UN/ISDR 2004).

Low demand can also be attributed to informational factors, including underestimation of flood risk, false sense of security, and myopic vision toward the future. People at risk can have drastically different degrees of risk awareness and estimates of risk hazard. In addition, lack of private sector insurance can also result from the unwillingness of property owners to purchase flood insurance unless damage is expected in the near future, thus leading to adverse selection problem. It is therefore imperative to assess the amount of information that potential policyholders might have and the way they process this information.

Similarly, a flood insurance scheme should clearly establish how it would be able to distribute the expected long-term loss burden geographically and over time, so that the individual bears only a small financial burden per unit of time. This is a difficult proposition to pursue since it requires consensus and political acceptability, especially for those people who (think they) would not be directly affected by flooding. Spreading risk and financial burden entails implicit subsidy from those less affected to those who are directly affected by flooding. France's flood insurance scheme appears to be successful because of the "solidarity principle" under which losses are distributed between both the calamity victims and those who do not suffer from the disaster. Therefore, greater public awareness and support for the program is important.

#### **D. Assess Partnership between Private Sector and Government in Adopting Flood Insurance**

Some country experience shows that governments are involved in almost all the countries that have flood insurance programs. None of these countries solely relies on market forces to encourage individual responsibility for reducing losses and insuring against these losses. Therefore, the success of a flood insurance depends on the close partnership among the government, the private insurance industry, and the public or policyholders. There are three types of flood insurance depending on the level of government involvement:

##### **1. Market-led Flood Insurance Scheme**

The private insurance industry is the main provider of flood coverage, while the government provides appropriate conditions for insurance cover, such as efficiently protecting the population at risk and reducing damage by means of mitigation regulations or protection measures, highlighting the threat and enhancing risk awareness among the population, mapping highly exposed regions, and providing flood defense infrastructure. A market-based flood insurance system that operates within a framework of flood defense provision by the government may be established through a partnership agreement among the concerned parties. In this case, a delineation of responsibilities must be well defined. For example, there is a need to specify the role of the government in terms of providing adequate level of capital and current expenditures on flood management activities, as shown in the case of the UK.

## 2. Government-led Flood Insurance Scheme

The government operates an insurance program and subsidizes or shoulders a large share of the insurance cost. At the same time, the government continues to build, operate, and maintain structural measures; provide compensation to flood victims; and control property development in flood-prone areas through stringent zoning regulations. This would likely lead to a worsening of the budget deficit. France's flood compulsory insurance program or "social solidarity" against flood damage is close to this scheme. Another example is a government disaster fund that acts as insurance system, similar to the one proposed in Hungary. This can be fully public, but privately administered and financed through mandatory contributions from all property owners. Contributions will not be based on flood risk and the government will continue to subsidize the purchase of insurance premiums for low-income households (Linnerooth-Bayer and Vari 2003).

## 3. Mixed Flood Insurance Scheme

A flood insurance program is operated by the private sector with substantial involvement from the government, such as imposing restrictions, providing information, subsidizing the premiums, and/or reinsuring the program. For example, the government commits to providing accurate information on flood damage and risks, and compensating flood victims by assuring their subsistence. The public role can be supplemented by a two-level private insurance program: mandatory (but bundled) insurance based on a flat-rate premium and, should households wish greater coverage, voluntary risk-based insurance, with the insurance premiums subsidized by the taxpayer.

Especially for a mixed flood insurance scheme, the government's role is rather complicated and entails careful assessment of some issues relating to (i) information on flood risks and damage; (ii) membership or participation in the flood insurance; (iii) predisaster and postdisaster assistance, and reinsurance; and (iv) reinsurance and institutional arrangements.

## E. Assess Specific Roles of Government in Flood Insurance Schemes

### 1. Improving Accuracy of Information on Flood Risks and Damage

Governments play an important role in improving information and awareness on risks and damage caused by floods. Flood mapping is usually undertaken to identify the risk. The cost is generally borne by the government. Drawing up of hazard zoning maps should involve stakeholder participation. Minimal local participation may create resentment, as what happened in France. Partnership with the academic community and research institutions can also facilitate sharing of research results on floods.

Flood mapping provides a good indication of demand for flood insurance. For example, demand for flood insurance in Australia's urban areas may be weak since the risk of urban flood is quite small, with only about 1% of the population considered at risk from river flooding (Paklina 2003). In contrast, flash floods, river flooding, and storm surges occur frequently, which make France's topography generally prone to flooding.<sup>15</sup> In the US, around 10 million households are estimated to be located in areas of significant flood risk. Flood mapping and the associated risk assessment may also provide insights on whether certain areas can still be covered by flood insurance. In the UK,

<sup>15</sup> The Ile de France area is a region of 11 million inhabitants, 800,000 of which are directly at risk from floods while another 2 million could be indirectly affected. Developments have sprouted in recent years that could increase the risk of flooding.



flood risk is becoming uninsurable in some areas due to a combination of various factors, such as increased frequency of heavy rains, poor maintenance of flood defenses, and inadequate investment in protecting properties that are built in flood-risk areas. In Australia insufficiency of reliable flood risk data was raised by the insurance industry as a major contributing factor to the scarcity of flood insurance products. Even in developed countries, the climate/flood insurance market is constrained by poor information and understanding of risks. Insurance companies are finding that past climate variability is a poor predictor of future risks, leading to volatile markets and cost of insurance.

Governments also need to promote flood risk awareness among the population living in flood hazard zones. This could be achieved by means of education, training, information collection, and dissemination of accurate flood data publicly; in particular, funding of research programs and studies (Paklina 2003). The Australian government stands as a good example of solid commitment to public awareness. It has undertaken a large number of reports and studies to improve information gathering and dissemination. Low awareness also means that even those at risk, but can afford weather-related insurance, do not consider buying a policy. A government-sponsored information program can inform the public of their exposure to flood risks and the personal benefits of having an insurance policy. These benefits are in the form of financial security that ad hoc emergency aid does not provide (Schwarze and Wagner 2004).

Moreover, overestimation of the extent of damage in the aftermath of a natural disaster often results in the disaster area being labeled as risk-prone, leading to withdrawal by private insurers. A rigorous hazard analysis would improve the accuracy of information on flood damage.

## **2. Imposing Mandatory or Optional Flood Insurance Schemes**

The analysis should assess the feasibility of a mandatory flood insurance given the socioeconomic context in a developing country. When flooding presents an imminent danger, a government may impose a compulsory flood and storm insurance. Alternatively, flood insurance can be combined or bundled with other insurance covers such as fire, storm, theft, earthquake, etc. In such a case, all major natural disasters (wind storms, floods, earthquakes, etc.) would be covered by a single insurance policy. This pooling approach increases the efficiency of risk coverage. By pooling previously distinct risk events, individual risk exposure can be guaranteed. A mandatory insurance can act like a tax/subsidy scheme that is contingent on the occurrence of a disaster. If well-designed, it can provide financial relief to affected policyholders and discourage population growth and land development in the floodplain. A standard argument against mandatory insurance, however, is that nonexposed homeowners are forced to purchase insurance that they do not need.

Under the optional insurance system, insurers agree to extend their policy to include flood upon payment of an additional premium. However, there are a number of problems with optional cover. Apart from the difficulty of defining floods, the biggest problem is adverse selection. Insurers tend to select against customers by making the cover available only in areas they consider to be safe, while customers select against insurers by only buying it in areas they deem to be risky.

## **3. Providing Postdisaster Relief and Compensation, or Subsidizing Predisaster Insurance Premiums**

Governments earmark financial resources for disaster relief to flood victims. Governmental risk management usually includes organization of financial and humanitarian aid, which could be channeled

through various government agencies, and subsequent repairs of damaged properties and provision of lifelines. Compensation is also provided to flood victims in some countries. Compensation mechanisms and hazard mitigation strategies vary considerably from one country to another because of differing national priorities and local cultures. These diverse national flood relief programs include: (i) systems with no state compensation for citizens (Germany, Japan, Portugal, UK); (ii) government policies providing for compensation during extreme hardships (Australia, Canada, Mexico, Slovak Republic, Turkey); and (iii) government catastrophe programs when a national disaster is declared (Belgium, France, Iceland, Italy, Netherlands, Norway, Poland, Spain, Switzerland, and US) (Paklina 2003).

Aside from postdisaster assistance, governments can subsidize predisaster insurance premiums, as what the US does. However, there are two issues that need to be assessed here: (i) the extent to which insurance premium should be subsidized in order to provide sufficient and affordable insurance coverage to the intended group, and (ii) whether the government can afford such subsidy. The former concerns the households' capacity to buy a flood insurance while the latter involves the government's fiscal capability in providing flood insurance subsidies. One should take cognizance of the fiscal impact of running the program. In the US, NFIP was initiated to address the increasing costs of government-funded flood management and disaster relief for flood victims. However, operating losses were experienced for some years because program costs were greater than the program's income. This occurred because losses from flood claims were greater than what could be paid by premium incomes collected from policyholders.

Thus, a planned flood insurance scheme should not be viewed as a direct replacement for government expenditures on flood management and disaster relief programs. A good understanding of its net fiscal impact in relation to the overall fiscal situation is needed, especially when such a program entails subsidies. This can be done through assessment of a country's present and medium-term budget framework, which indicates government capacity to finance planned flood insurance scheme and subsequent recurrent spending.

#### **4. Providing Reinsurance and Undertaking Analysis of Institutional Arrangements**

Other options open to governments include conventional insurance and reinsurance in international markets, group insurance with other vulnerable countries, or self-insurance through national funds underwritten with novel financial instruments (DFID 2004). After clarifying the level of government involvement in insurance provision, institutional analysis needs to be undertaken to assess the performance of government institutions in the areas of delivering timely and relevant information on flood risks, disaster warning, relief operations, political and administrative responsibilities, among other things. In many instances, flood protection involves a myriad of agencies and institutions from the national, to regional, and down to the local level. Simple and streamlined institutional arrangements for decisionmaking could help reduce exposure to flood risks of policyholders and the insurance industry.

## V. OPERATIONAL IMPLICATIONS FOR ADB

In the previous decades ADB operations pertaining to flood management employed a top-down, engineering approach, which was predominant in large-scale investments. Dams have significantly figured in ADB's development efforts, with 65 dam projects approved from 1970 until mid-2005. Recent ADB projects on flood management gear toward a combination of structural and nonstructural measures, such as embankments, flood zoning, forecasting and warning systems, and institutional capacity building. ADB has also been encouraging integrated flood management as a way to reduce the economic and social costs associated with extreme flooding. ADB has approved 17 loans on flood management amounting to US\$1.2 billion during the period 1968–2006. It adopted its water policy, *Water for All* (ADB 2001), which aims to “adopt a proactive approach to reduce the severe economic and social costs of natural disasters by promoting the use of combined structural and nonstructural approaches to flood protection, including flood risk insurance.” Between 2001 and 2006, ADB implemented 11 technical assistance grants (TA) totaling about US\$7 million (financed through various sources), and approved six loans amounting to US\$573 million, all of which dealt with flood management and risk mitigation.

ADB's water policy provides for a cautious approach to large water resource projects, especially those involving dams. While ADB has been engaged in a number of dam-related reviews and discussions, these forums rarely scrutinize the correlation between structural measures and long-term population changes. Borrower proposals for structural flood measures need to be evaluated more cautiously because these may well be socially suboptimal given their limited time horizon. Box 4 shows some considerations for ADB involvement in flood management measures.

### Box 4 CONSIDERATIONS FOR ADB INVOLVEMENT IN FLOOD MANAGEMENT

- Evaluation of borrower proposals for structural flood measures needs to take into consideration various factors, such as fiscal burden, redistributive feature, risk mitigation, and population and land use. Cost recovery mechanisms must be able to provide a disincentive for migration and business development in the floodplains.
- Least-cost analysis of structural measures for flood management must be undertaken in comparison with nonstructural measures.
- ADB could assist in exploring and enhancing the desirability and feasibility of adopting flood insurance in its developing member countries (DMCs), particularly through:
  - promotion of knowledge and information sharing
  - assistance in institution building
  - enhancement of risk-pooling measures and product designs
  - pilot testing for possible scaling up or replication
- Technical assistance resources can be mobilized to generate and share knowledge in risk mapping, awareness promotion, institution building, feasibility studies, etc. Once sufficient experience and knowledge have been accumulated, ADB might be in a position to consider some regional initiatives. One example is the issuance of regional cat bonds, which have increasingly received attention since the Asian tsunami and bird flu outbreak.

Despite the provision of ADB's water policy on flood protection, flood insurance is rarely discussed in ADB's flood management operations. Much needs to be done to fully explore the potentials of flood insurance as a mitigation measure. One possible option for ADB is to identify

innovative approaches for making flood insurance affordable and to assist developing member countries (DMCs) in short-term recoveries in the event of large-scale flooding. In particular, ADB can consider the following.

- (i) *Promotion of knowledge and information sharing.* ADB could help inform the design of flood insurance programs through promotion of learning and knowledge sharing. This can be done by undertaking appropriate special studies and providing technical assistance that explore the potentials of flood insurance in Asia and the Pacific region as an alternative to structural or engineering interventions. ADB can also encourage better practices on flood insurance design through seminars, symposia, and other fora for ADB staff, DMC government officials, private insurance firms, consultants, and practitioners. Future initiatives that deepen understanding on flood insurance scheme can focus on (i) examining the linkage between flood–poverty reduction and flood management/rehabilitation in the Asian context; (ii) assessing the state of the private insurance industry and extent of underprovision; (iii) addressing affordability issues and information gaps; (iv) exploring government–private insurance and policyholders/community partnerships; and (v) assessing modes of flood insurance participation (e.g., mandatory or optional system). Political economy considerations in designing flood insurance and the possible impact of flood insurance in reducing a government’s fiscal burden could also be the subject of future inquiries.
- (ii) *Assistance in institution building.* ADB can promote adoption of holistic disaster management policies or strengthening of existing institutional framework in its DMCs. Some countries in Asia have considerable achievements in this field. In South Asia for instance, disaster planning and relief are institutionalized in most countries—Disaster Management Bureau in Bangladesh, Federal Flood Commission in Pakistan, Disaster Relief Committees in Nepal, and National Disaster Management Center in Sri Lanka. However, institutional capacities to address flooding problems generally remain weak. Some institutions (e.g., the local level Disaster Relief Committees in Nepal) have yet to operate on a regular and full-time basis. Another aspect in which ADB’s expertise may be needed in the future is on assisting DMCs in setting up legislative frameworks and policies for the development and operation of the private insurance industry.
- (iii) *Enhancing risk-pooling measures and other innovative approaches.* Poor households cannot recover from the impact of a large disaster unless the size of the risk pool is correspondingly enlarged. If the vulnerable households have access to adequate risk-pooling measures, the outcome and impact of flooding could be mitigated. ADB can actively promote or enhance risk-pooling measures to effectively mitigate consequences of flooding, especially among the poor groups. For example, ADB can explore the possibility of supporting group self-insurance organized by nongovernment organizations (NGOs). A cash pool can be established through contributions by households living in flood-prone areas.

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Cash pool funds may be used for on-lending to members affected by floods. ADB could support such initiatives through measures that enlarge the cash pool and strengthen the institutional mechanisms that extend insurability to vulnerable groups.

ADB can also promote the use of catastrophe financing instruments. Catastrophe bonds work through the creation of a trust account by an insurance company that enters into a reinsurance contract with the insured entity (e.g., risk-prone government). The company then issues the bonds to investors. If there is no catastrophe and no loss occurs, investors receive a return of principal and a flow of interest payments that compensate them for the use of their funds and their risk exposure. However, should a predefined catastrophic event occur, investors lose their principal, interest, or both, and these funds go to pay off the insured entity (DFID 2004).

- (iv) *Pilot testing for possible scaling up or replication.* ADB could support the pilot testing of innovative flood insurance schemes to assess their affordability to vulnerable groups. In addition to its advisory role in the pilot testing, ADB could also consider involvement in underwriting design costs, coordination of governments and private insurance companies, subsidizing insurance premiums, and investing in an equity layer of the scheme. Insights from these pilot testings would facilitate scaling up or replication elsewhere, including possible link-ups with international insurance markets. This can be undertaken through a technical assistance facility that would systematically evaluate the outcomes, impacts, and feasibility of a flood insurance scheme. In this case, the scope of the Asian Tsunami Fund may be broadened to finance such activities.

## VI. CONCLUSIONS

Sustaining traditional responses to flooding (e.g., engineering interventions, disaster relief programs, or compensation to flood victims) have become difficult for many governments because of the increasing financial implications brought about by repeated occurrences of flood disasters. Moreover, structural measures favor the intensification of land use and population growth within the floodplain. Greater private sector participation through transfer of a portion of liability for flood losses to individuals and wider risk-sharing will reduce a government's fiscal burden, while at the same time, help discourage migration and development in flood-prone areas. In light of perennial flooding in the Asian region, flood insurance has been increasingly seen as one of the nonstructural flood management tools that could mitigate economic losses and reduce vulnerabilities of the population, especially of the poor groups.

Reliance of flood insurance on market forces encourages individual responsibility for minimizing flood losses and insuring against them. Therefore, a well-designed flood insurance scheme should promote greater sharing of risks and cross subsidies to poor groups. It should take into account existing political economy considerations since a flood insurance scheme should be viewed as fair, viable, and sustainable by the private insurance industry, policyholders, and the government. However, design issues and challenges in designing a flood insurance scheme appear to be complex. There is limited relevance in proposing a "one-size-fits-all" flood insurance scheme given the context-specificity of flooding. Also, there is no generally accepted international best practice in flood

insurance. Diversity in design-related issues and experiences of various countries tend to support this.

Given the need to explore alternative responses to flooding, ADB can play a role beyond what it has enunciated about flood insurance in its water policy. Relevant and value-adding country-specific advisory assistance from ADB would be needed for testing and designing a feasible flood insurance scheme.

## APPENDIX A

### How Population Changes Lead to Construction of Oversized Dike in a Floodplain: A Theoretical Model

We establish a human behavior model in which people make decisions to settle in a particular area based on the cost of living. The cost of living in a nonflood plain is assumed to be fixed, while the cost of living in a floodplain depends on the size of the structural measure. To illustrate our idea, we ignore all the construction technicalities of the structure, and measure and assume that the flood mitigation effectiveness of the dike completely depends on the size, i.e., the higher the dike, the less likely the occurrence of flood. The model shows that people's migration decisions lead to a dike size that is bigger than socially optimal. The reason is simple. In each period, the floodplain inhabitants optimize the dike size (height) by balancing the flood mitigation benefits and construction costs. Consequently, more people are attracted to the floodplain because of the reduced costs of living. In the next period, the new floodplain population would decide to further increase the height of the dike because the individual share in the dike construction cost goes down with the increase in population. This process will continue until such a time when no more new migrants are attracted into the floodplain. As a result, greater floodplain populations and larger dams become a self-sustaining and self-reinforcing process.

#### Model Assumptions

##### 1. Population

Total population size is  $N$ . Some people live in the floodplain; others in the nonfloodplain. All the people are identical except at the initial period in which they live in different distances from the floodplain. Therefore, individual  $i$  can be labeled by his travel costs to the river denoted by  $c_i \in [0, T]$ . In other words, the  $i^{\text{th}}$  person incurs a travel cost of  $c_i$  in migrating into the floodplain. The distribution of population is assumed to be continuous and denoted by the distribution function  $f(c)$ , with  $F(c)$  being its cumulative form. Therefore,  $F(0)$  is the population size living in the floodplain  $F(T)=N$ . Initially, there are  $F(0)=n^0$  people living in the floodplain and others in the non-floodplain.

##### 2. Flood and Flood Disaster Relief

The probability of flood in the floodplain is denoted by  $q^t$  where  $t$  is the time superscript. The probability of no flood is therefore  $1 - q^t$ . Dam construction affects  $q^t$ ; a bigger and more costly dike has a smaller  $q^t$ . At the initial period, the flood probability is  $q^0$ .

A dam will decrease the chance of flooding  $q^t$  with a construction cost function of  $D(q^{t-1}, q^t) = D(q^t) - D(q^{t-1})$ , with  $D' < 0$ ,  $D'' < 0^t$  and  $D(q^0) = 0$ . This reflects that, at any time  $t$ , given  $q^{t-1}$ , the lower  $q^t$  is required, the bigger/higher the dike has to be, and the greater construction cost will be. The cost of dike construction is disproportional to the dike size, i.e., big dikes cost significantly more than small ones. Construction cost will be equally shared among the contributing inhabitants.

##### 3. Income

We assume people living in the floodplain will receive an income  $H$  if there is no flood. They receive  $L$  if there is a flood. The  $i^{\text{th}}$  person pays  $c_i$  to move into the floodplain. People living outside of the floodplain receive a universal income  $Z$ . For simplicity, people are assumed to be risk-neutral and to maximize their expected income. At the start, we assume:  $(1 - q^0)H + q^0L = Z$



## Benchmark: Social Planner's Choice of Population and Dike Size in the Floodplain

Before examining the interactive process between dike construction and floodplain population change, we first discuss the optimal size of the population and dike in the floodplain. We consider a social planner setting in which the social planner is able to decide the size of the dike that maximizes welfare of all the people—including both floodplain residents and nonfloodplain residents—and collect dike construction costs from all the potential beneficiaries—including both the floodplain inhabitants and the potential migrants. For the potential migrants, this charge will be an “admission fee” to the floodplain. This assumption is not realistic in the real world, but it gives us a benchmark of the “optimal” size of the dike construction and population in the floodplain.

This scenario gives rise to what we will call Policy 1. The social planner announces the size of the dike and collects the construction cost equally from the existing residents and future migrants. Future migrants are charged with a flat entrance fee to the floodplain area.

The social planner aims to maximize welfare of the whole population, both in the floodplain and in the nonfloodplain, by choosing the dike size. Once the dike size has been determined, the planner expects part of the nonfloodplain inhabitants to move into the floodplain, hence balancing the net benefit difference between living in and outside the floodplain, their travel costs, and their shares of dike construction costs. The dike construction costs are shared equally among the original floodplain inhabitants and new immigrants. The social planner's problem is stated as follows:

$$\text{Max}_q \quad n[(1-q)H + qL] - \int_{i=n^0}^n c_i + (N-n)Z - D(q) \quad (1)$$

$$\text{s.t.} \quad (1-q)H + qL - c_i - \frac{D(q)}{n} \geq Z \quad \text{for } i = n^0, \dots, n \quad (2)$$

$$(1-q)H + qL - c_n - \frac{D(q)}{n} = Z \quad (3)$$

where  $n$  is the population size in the floodplain and  $q$  is the probability of the flood after the dike is constructed. The objective function (1) states that the social planner maximizes all the people's expected income. It has four terms. The first term is the sum of expected income of all the people who live in the floodplain. The second term is the migrants' travel costs. The third term is the total income of the people who stay outside the floodplain. The last term is the cost of dike construction.

Conditions (2) and (3) specify people's migration decision. People make their migration decision based upon the comparison of expected income in and outside the floodplain. Equation (2) says that people will move if the net benefits of living in the floodplain, minus their travel costs and their shares of dike construction costs, are greater than those of living in the nonfloodplain. Otherwise, they will stay in the nonfloodplain. People who have lower travel costs would therefore migrate first. The last person to migrate is  $n^{\text{th}}$  person who is indifferent between migrating or staying in the nonfloodplain, which is shown in Condition (3). Condition (3) says the migration will stop at the last person  $n^{\text{th}}$  whose expected income in the floodplain, minus his travel cost and his share of dike construction cost, is equal to his income outside the floodplain  $Z$ , the opportunity cost of migration.



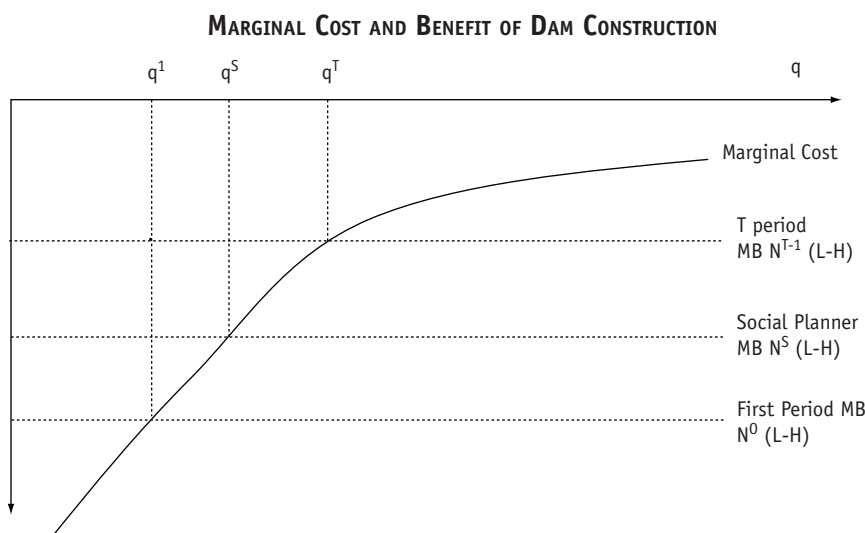
The objective function is maximized subject to people's migration decision. The condition states that once the social planner identifies the potential immigrants—the  $q^s$  has to be such that it is to the people's interests to move. First order condition yields the optimal solution  $q^s$ :

$$-D'(q^s) = n^s(H - L) \quad (4)$$

$$(1 - q^s)H + q^sL - c_{n^s} - \frac{D(q^s)}{n^s} = Z \quad (5)$$

where  $n^s$  and  $q^s$  with superscript  $s$  is the social optimal level population size and dike size that maximize social welfare. Equation (4) says the dike will be constructed to a size that equates marginal increase in net benefits of living in the floodplain with the marginal cost of dike construction. The bigger the population living in the floodplain, the larger the size of the dike becomes. Equation (5) is the migration condition. As long as the planner sticks to the announced admission fee even after the dike is constructed, there will be no subsequent migrants and no tax revenues (see Appendix Figure 1).

APPENDIX FIGURE 1



### Reality: Interactions between Dike Construction and Migration

However, reality departs from the above benchmark model in two ways. First, it is hard to conceive how the social planner could credibly announce the size of the dike and collect the dike construction charges from future migrants even before the dike is constructed. Second, implementing the admission fee scheme is politically problematic in many cases. After the dike has been constructed and the construction costs fully recovered (paid), those who live far from the floodplain may free ride by migrating without paying the dike construction cost. It is difficult to see how the social planner could keep them out of the floodplain. So it is much more realistic to assume the following second policy.

In Policy 2, the dike construction cost can only be shared among the people who have, at the time point of dike construction, lived in the floodplain. People can subsequently migrate and free-ride the dike as long as doing so is to their interests. Therefore, we specify the following timeline in a repeated game setting:

## 1. Timeline

There are infinite time periods. The timeline of the events in each period is as follows:

- (i) *Dike Construction.* The floodplain residents collectively, or through their local governments, decide on flood mitigation measures (e.g., dike size) by balancing the benefits and construction costs involved.
- (ii) *Migration.* People then make decisions about their living locations. We assume people respond to current period payoffs in a very simple manner: If the net benefits of living in the floodplain are higher than the sum of the net benefits of living in the nonfloodplain and travel costs, they will move into the floodplain,<sup>16</sup> and vice versa.
- (iii) *Benefit Realization.* People's net benefits are realized depending on their locations (floodplain or nonfloodplain).

For each period, floodplain inhabitants collectively decide on dike construction and share the construction costs. Dike construction improves the net benefits of living in the floodplain. Consequently, some people living outside the floodplain will be attracted to migrate into the floodplain and incur travel costs. Besides the travel costs, no other mobility constraints are assumed—original floodplain inhabitants are unable to tax them for the already-constructed dike, so new migrants are in a sense “free riders” of the dike, which is a public good. In the model, new migrants or population changes in the floodplain do not alter the net benefits of residing there. Hence, it is easy to assume that the original inhabitants would build the dike without considering its effects on the migration. In other words, they would not behave strategically to deter or encourage migration in any period.

## 2. Dike Construction

Denote time periods with superscript  $t=1,2,\dots$ . In each period, the floodplain inhabitants,  $n^{t-1}$ , decide on the size of the dike ( $q^t$ ) and share the construction cost  $D(q^t) - D(q^{t-1})$ . The maximization problem is as follows:

$$\text{Max}_{q^t} (1 - q^t)H + q^tL - \frac{D(q^t) - D(q^{t-1})}{n^{t-1}} \quad (6)$$

The first two terms are the expected net benefits of the floodplain inhabitants. The last term is the additional construction cost of the dike at that period. The first order condition yields:

$$-D'(q^t) = n^{t-1}(H - L) \quad (7)$$

The equation states that the dike will be constructed to a size that equates marginal increase in net benefits of living in the floodplain with the marginal cost of dike construction. The bigger the population living in the floodplain, the larger the size of the dike becomes.

## 3. Migration Decision

In each period after the dike is constructed, the net benefit of living in the floodplain is changed. Dike construction improves the net benefits of living in the floodplain. Consequently, some people living outside

<sup>16</sup>Including the consideration of people reacting strategically and moving out of the floodplain in the first period and moving back in, does not add insights in our model, so we do not consider it here.

the floodplain will be attracted to migrate into the floodplain by incurring travel costs. Those living closer to the floodplain have smaller travel costs, and hence, are more likely to move. The new migrants are:

$$(1 - q^t)H + q^tL - c_i \geq Z \quad \text{for } i = n^{t-1}, \dots, n^t \quad (8)$$

$$\text{where } (1 - q^t)H + q^tL - c_{n^t} = Z \quad (9)$$

The equations state that people will move if the net benefits from living in the floodplain, minus their travel costs, are greater than those from living in the nonfloodplain. Otherwise, they will stay in the nonfloodplain. The  $n^{t-1}$ th person has the lowest travel cost among the people living in the nonfloodplain and would therefore migrate first. The last person to migrate is  $n^t$ th person who is indifferent between migration or staying in the nonfloodplain.

Therefore, in the first two periods:

$$D'(-q^1) = n^0(H - L) \quad n^1 = F(c_{n^1}) = F[(1 - q^1)H + q^1L - Z] \quad (10)$$

$$D'(-q^2) = n^1(H - L) \quad n^2 = F(c_{n^2}) = F[(1 - q^1)H + q^1L - Z] \quad (11)$$

The interactions between dike construction and migration decisions are as follows: In the first period, the larger the initial floodplain population  $n^0$  is, the bigger the dike is going to be ( $-q^1$ ). A bigger dike attracts more people to migrate ( $n^1$ ). In the second period, a large  $n^1$  will lead to a bigger dike and more migrants ( $-q^2$  and  $n^2$ ), and so on and so forth.

### Comparing Policy 1 and Policy 2 in Terms of Population Size and Dike Size

It is easy to see from the above that the population in the floodplain will keep increasing, and so will the size of the dike. From Equation (5), it is clear that

$$\because n^0 \leq n^s \quad \therefore \quad q^1 \geq q^s \quad (12)$$

This means that in the beginning, the population size and dike size are smaller than the benchmark levels. In the second policy scenario, the population size and dike size keep increasing. Suppose at time period  $t-1$ , the size of the dike  $q^{t-1}=q^s$ . From Equation (9) and Equation (7) we find:

$$n^{t-1} \geq n^s \quad (13)$$

$$q^t \leq q^s \quad (14)$$

Equations (13) and (14) state that at a certain time period, the size of the dike will reach the benchmark level. In the next period, the population size in the floodplain will exceed the benchmark level and will lead to the construction of a bigger dike.

The problem described in the above interactive process lies in the fact that the decision on dike construction by the floodplain inhabitants does not take into consideration its impact on future migration. It boils down to who should pay for construction of the dam/dike. In reality, after the dike has been constructed, the increased safety of the floodplain area is a public good, which attracts migration and further construction of the dike. These migrants pay, in our cases, zero cost of dike construction and full cost of travel, so their migration decision is suboptimal from the society's point of view because too high travel costs have been incurred in moving to the floodplain. Where migrants pay for the dam indirectly through higher city or county taxes or property prices, this problem might be partially alleviated. However, as long as the payment does not fully internalize the dam construction costs, our result stands qualitatively unchanged.

This result is of interest because it contradicts the conventional wisdom that the positive externalities of the public goods lead to undersupply of the goods. However, in our case, the public good nature of the dike leads to the oversupply of the dike because the dike distorts the migration incentives of the nonfloodplain inhabitants, and consequently leads to socially inefficient location decisions.

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