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Research article

Risk-trading in flood management: An economic model

Chiung Ting Chang

National Sun Yat-sen University, Institute of Public Affairs Management, Kaohsiung, 804, Taiwan

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ABSTRACT

Although flood management is no longer exclusively a topic of engineering, flood mitigation continues to be associated with hard engineering options. Flood adaptation or the capacity to adapt to flood risk, as well as a demand for internalizing externalities caused by flood risk between regions, complicate flood management activities. Even though integrated river basin management has long been recommended to resolve the above issues, it has proven difficult to apply widely, and sometimes even to bring into existence. This article explores how internalization of externalities as well as the realization of integrated river basin management can be encouraged via the use of a market-based approach, namely a flood risk trading program. In addition to maintaining efficiency of optimal resource allocation, a flood risk trading program may also provide a more equitable distribution of benefits by facilitating decentralization. This article employs a graphical analysis to show how flood risk trading can be implemented to encourage mitigation measures that increase infiltration and storage capacity. A theoretical model is presented to demonstrate the economic conditions necessary for flood risk trading.

1. Introduction

Although it has long been recognized that in flood management human factors need to be taken into account in addition to natural factors, methods of flood management that integrate human and natural factors are not yet well developed. Early approaches applied empirical results of hydrological studies to welfare analysis (Pattanayak and Kramer, 2001; Jepsen, 2003). Models of this sort are limited to studying the implications of economic decisions, and fail to incorporate environmental factors endogenously.

A second approach is to estimate the impacts of environmental hazards using dose or damage functions. This methodology is widely used to evaluate the impacts of pollution and the effects of pollution control measures on public health (Alberini et al., 1997; Machado and Mourato, 2002) in addition to flood management (Jonkman et al., 2008). The second approach makes it possible to make an empirical estimation, but it does not help to generate guidelines for making public policy decisions directly. Moreover, in order to respond to changing socioeconomic and natural processes and concomitant measures to reduce flood risk, flooding systems are continuously in flux. Drawing policy implications from damage estimation is therefore limited.

The third approach, the production function approach proposed by Freeman and Harrington (1990), aims to endogenize both environmental quality and averting behavior taken from welfare analysis. This approach is also limited, however, as it is implicitly based on the assumption of perfect foresight, while uncertainty is a significant feature of flood events. This problem is found in the first two approaches as well.

Modern concepts of flood risk management involve community and public participation, in addition to expert opinion and policy guidance (Hall et al., 2003). The concept of integrated assessment in flood risk management is supposed to take multiple options into consideration, such as various types of hard engineering measures, soft engineering measures and land use management. While a shift towards a more integrated approach is taking place in flood risk management, research continues to be mostly based on specific case studies of governance (Hall et al., 2003; van Herk et al., 2011; Ward et al., 2013). And although flood risk management has shifted from a technical-oriented approach towards a political-oriented approach via the integrated river basin approach (Thaler and Levin-Keitel (2016), putting the idea of an integrated approach into practice has been challenging (Blomquist and Schlarger, 2005).

A general lack of coordination between state and local authorities has long been recognized in the area of water resource management (Caruso, 2000; Roy et al., 2008). Integrated river basin management has been the experts' choices, but decisions about land and water resources involve value choices that concern various communities of interest (Blomquist and Schlarger, 2005).

E-mail address: ctchang2013@mail.nsysu.edu.tw.

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The costs and benefits of river basin management are often separated spatially and are borne by different parties. Upstream land owners are typically service providers while downstream land owners are beneficiaries. Postel and Thompson (2005) suggest in this regard that establishing equitable partnerships between beneficiaries and providers is a key challenge in designing workable mechanisms in an integrated approach.

Moreover, there is scepticism about the reality of reaching consensus in both theory (Buchanan and Tullock, 1962) and practice. Trying to achieve consensus in practice often leads to either gridlock as individuals exercise their veto power, or to a something-for-everyone form of distributive policy. Competing values may go unheard or be suppressed, and the issues may be too narrowly framed (Blomquist and Schlarger, 2005).

Instead of consensus, aggregating opinions is a possible alternative. Brouwer and van Ek (2004) apply both cost-benefit analysis and multi-criteria analysis to make an integrated impact assessment of flood control policies. The authors acknowledge, however, that the outcomes of applying cost-benefit analysis and multi-criteria analysis are highly sensitive to the assumptions underlying those methods. Vrana et al. (2012) introduce an optimum aggregating method to maximize the agreement of experts' opinions on environmental issues like flood impact mitigation. However, uncertainties in the performance and cost as well as insufficient engineering standards and guidelines, suggested in Roy et al. (2008), remain as impediments to applying the above method. Apart from presenting barriers to obtaining watershed-scale urban storm water management, Roy et al. (2008) also propose some solutions, including cap-and-trade programs. However, the research does not elaborate on these programs.

Even if the difficulties of implementing integrated river basin management can be overcome, problems relating to public choice remain. Blomquist and Schlarger (2005) suggest that integrated river basin management might do a better job of trading flood risks versus channel conditions, groundwater recharge, and habitat protection, but not flood risks versus a municipal auditorium. This is where a market-oriented approach like a flood risk trading program could play a role, with its capacity to incorporate various types of interests and values.

Trading emission reductions was the first application of a trading mechanism in environmental management. The idea was born out of literature such as Pigou (1938[1920]) and Coase (1960). Chang (2008) introduced a tradeable flood mitigation permit (TFMP) system, initiating a discussion of risk-trading in flood management. Risk-trading occurs when a region, possibly but not necessarily a flood risk receptor, obtains financial benefits from a flood risk sender whose risk is reduced due to measures taken by the flood risk receptor. Three types of TFMP are possible, each subject to its own set of institutional conditions. Where a change in land use generates significant impacts with respect to flood risk, the application of *tradeable development rights* (TDR) can ensure that a certain amount of land is preserved for specific use, either indirectly serving as a flood buffer or directly avoiding development in flood-prone areas. *Tradeable flood reduction* permits (TFR) allowing all types of mitigation measures to enter the market are an option when hard engineering measures are necessary for catchment flood mitigation. When the adverse externality caused by hard engineering measures is significant, *tradeable risk neutral* permits (TRiNe) are recommended to achieve an externality-free result or to partially offset an adverse externality.

Chang and Leentvaar (2008) use the case of the Rhine river to illustrate how risk-trading can work in a transboundary river basin. In the empirical case involving the German and Dutch sections of the Rhine river, Germany adopted soft engineering measures to mitigate not only downstream flood risk in the Dutch region, but also its own flood risk. The case demonstrates that flood risk trading need not only occur between risk sender and risk receptor. It is likely that both the seller and the buyer involved in a flood risk trading program benefit from flood risk reduction. Apart from discussion on program design, further study is needed of optimal economic conditions for specific as well as models of flood risk trading.

The classic model of optimizing hard engineering flood mitigation measures was introduced by van Dantzig (1956). He developed a model for minimizing the total construction cost of a dyke and the present value of expected flood losses with respect to the water level the dyke is capable of retaining. Although the model was intended for optimizing hard engineering mitigation measures, application of its expected value theory to modelling decisions with respect to other mitigation measures also merits exploration. An expected welfare function aggregates individuals' utility into social utility, which can be applied to regional decisions respecting flood management. The function is also helpful for measuring social welfare in cases of policy analysis involving uncertainty about future events (Crew and Kleindorfer, 1976; Drazen and Grilli, 1993).

Croghan's (2010) attempt to model a flood risk trading program is restricted to the damage function approach. Ward (2013) demonstrates an optimization model for the application of tradeable development rights in flood management. While the element of uncertainty is taken into account, application of Ward's model is limited to options of land use change, which represents only one of the possible options in flood risk management. The model does emphasize efficiency improvement in flood management through application of tradeable development rights, but fails to examine the necessary conditions for trading.

This article presents a theoretical model that outlines decision rules for the option of flood risk trading. This model provides for the incorporation of both hard and soft engineering flood mitigation measures, and facilitates discussion of the requisite economic conditions for a flood risk trading program. Both economic and environmental conditions are taken into consideration.

2. The prototype

Let us first consider a bilateral negotiation in which two regions aim to maximize their respective expected economic return. They negotiate to reach an agreement on the acceptable level of flood risk and the relevant amount of economic compensation. The possibility of multiple participants in practice will be discussed in Section 5.

Each region may choose to increase discharge capacity, storage capacity, or infiltration capacity in order to mitigate flood risk. Discharge capacity could increase flood risk while storage and infiltration capacity could decrease flood risk of its hydraulically related region(s), such as downstream or in neighboring region(s). Mitigation measures that help to increase discharge capacity are embankment, pumping facilities, drainage and flood gates, for example. Measures that increase storage or infiltration capacity are retention ponds, natural vegetation and managed retreat. Development of land may increase discharge capacity while generating economic returns.

The maximization problem of a regional social planner can be written as follows:

$$\begin{aligned} &\max EW = \max \sum_{n=1}^{N} P_n(l,m)\cdot W_n(l,m) \\ &\text{s.t.} \quad 0 \le l \le L \\ &\qquad 0 \le c\cdot m \le w \end{aligned} \tag{1}$$