MicroWorlds as a Tool for Policy Making

Lisa Brouwers and Karin Hansson

Dept of Computer and System Sciences
Stockholm University and KTH
Forum 100
SE-164 40 Kista

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Abstract

The Hungarian government is experiencing escalating costs for flood mitigation measures and for economical compensation to victims. In a joint research project between the International Institute of Applied System Analysis (IIASA) in Austria, Computer and System Science Department (DSV) in Sweden, and the Hungarian Academy of Science, the flooding problem of Upper Tisza in Hungary is investigated. A catastrophe simulation model has been implemented, where different policy options are tested and evaluated. We investigate how the willingness to buy insurance affects the results on the macro-level and on the micro-level.

Contents

1 Introduction **3**

2 Simulation Model **5**

3 Mathematical Representation **6**

3.1 Wealth transformation function for each Property agent 7

3.2 Wealth transformation function for Local government agent . . 7

3.3 Wealth transformation function for each Insurer agent 7

4 Policy Simulations **8**

5 Results of the Simulations **8**

6 Conclusions **12**

1 Introduction

The economic losses from floods are escalating. One reason is that the severity and frequency of floods are increasing. Climate change may be one of the explanations of this phenomenon; a warmer atmosphere absorbs more moisture, which leads to increased precipitation as a part of the heating will go into evaporating larger quantities of water from the surface of the earth. The atmosphere is also capable of supporting greater amounts of water vapour. In general, an increase in the proportion of extreme and heavy precipitation events would occur where there is enough atmospheric instability to trigger precipitation events. This intensification of the hydrological cycle means more flooding with an increase in extreme precipitation events according to [4]. Another reason has to do with land-use changes; there has been a concentration of people and vulnerable assets in flood-prone areas during the last years.

In Hungary, the costs for protection of flood and compensation to victims are by tradition considered the responsibility of the government [6]. The Hungarian government is looking for new loss-sharing mechanisms. The government is investigating the possibilities to transfer part of the economic responsibility from the government to the individuals. A reason for this intension is that the government is under press to lower its expenditures in order to pass the economical requirements in order to be accepted as a new member of the European Union. Another motive is that the government has a desire to implement a system that is fairer, a system where the flood risk of the geographical locations affects the degree of responsibility. A person living in a flood prone area should contribute more than a person living in a safe area should. The current situation is that all taxpayers contribute equally and share the majority of the cost trough their income tax. A financial mechanism, like private insurance is one possible method for better reflecting the risk level of a certain area. The size of the premiums may reflect the flood risk of a location. Differentiated premiums can besides giving a fairer distribution of the economical responsibility also be seen as an incitement for a sounder land-use.

The implementation of a National Insurance system is a complicated policy problem. It is vital that the different stakeholders support the policy before it is implemented. One of the important stakeholders is the insurance industry. Insurers normally regard flooding as uninsurable. With escalating losses, many insurers are reducing their catastrophic cover. In Hungary, only a few companies offer insurance against floods. Moreover, the insurance contracts that are offered are connected with a number of limiting conditions; ground water related floods are for instance excluded. Many times it is difficult to tell if the flood is caused by intense precipitation, by a failure of some flood protection, by ground water elevation, or if it is caused by a combination of these factors.

The relative infrequency of catastrophe events and the resulting scarcity of historical loss data make it nearly impossible to reliably estimate catastrophe losses using standard actuarial techniques. However, recent advances in computer modelling of catastrophic events have increased the interest to offer flood insurance. By combining mathematical representations of the flood occurrence, with information on property values, construction types etc., simulation models that generate loss estimates can guide insurers and other policy makers. For such a catastrophe simulation model to be useful, it must demonstrate the spatial and temporal dependencies specific to the studied area, and specific to each stakeholder in the region. In order to investigate

Figure 1: Basin 2.55, the study area for the Tisza Project.

the effects of different flood management strategies for Upper Tisza in Hungary, an executable simulation model of the river basin has been built. In Figure 1 the basin investigated is presented. Before real data from the basin was available, a prototype model was used to perform initial experiments, see [1, 3]. These experiments indicated what features to improve or leave out in the real simulation model, which is described in next chapter.

2 Simulation Model

A river is affected by many systems, and the river affects these systems. The probabilities for a flood to occur in a river, and the economic consequences from a flood are strongly connected with systems of economy, ecology, meteorology, and hydrology. In all these systems, uncertainty is inherent. For complex problems, the use of a generalised representation, a model of the problem, is commonly used. The problem of investigating different policy strategies for flood mitigation is indeed complex as it is impossible to predict what state the system will be in at a certain time. By simulating the change of states, different policy strategies can be tested and evaluated on the model. A policy strategy is here a combination of one or more policy alternatives. An example strategy is *"Levee height at location 1: 5 metres, levee height at location 2: 3 metres, levee height at location 3: 2 metres, Compensation level from the government: 30 per cent, Premium levels: 3 per cent of property value"*. The catastrophe simulation model consists of

Figure 2: Modules in the system.

several modules; see Figure 2. The stochastic variables (i.e., water-level, precipitation, discharge) are assigned new random values from the specified distributions in the Monte Carlo module each round of the simulation. The random outcome, the values of the stochastic variables telling what state the system is in, is passed to the Catastrophe module. This module contains a hydrological model and an inundation model, both developed in Hungary by Vituki Consulting [7]. The Catastrophe module calculates how the water overflows the levees in case of a flood, what land areas are inundated, and by how deep water. The Consequence module consults the Spatial Module for information on property values for the inundated cells. For each cell where there is flooded property, the economic consequences for all concerned agents are calculated and their wealth is updated accordingly. The different agents represented in the model are the property agent, the insurer agent, and the governmental agent. For a more exhaustive description of the agents, see [2]. The economic consequences depend on the current policy strategy. For each year (here represented as one simulation round) the Policy and Optimisation module evaluates the success of the current policy strategy with regard to the stated goal function. If the optimisation feature is turned on during the simulations, the policy strategy is slightly altered, in the direction that seems most promising trough an automated dynamic adaption. The search space can be further delimited by different constraints; and violations against these are checked before a new policy strategy is generated. This process of adaptive Monte Carlo simulation is described in detail by [4].

3 Mathematical Representation

Let X be the set of all possible policy strategies, then x_i is one specific policy strategy. The strategy described earlier is an example of such a strategy. The set Ω contains all states the system can be in, each state is described by the values of the stochastic variables. A certain state is for instance, ω_7 a vector with the following values of the stochastic variables, *"Amount of precipitation: 37 mm, Water level: 7 m, Discharge: 12"*. During our simulations, the vector (contains only one variable, $flood$. The hydrological relationship between water-speed, temperature, wind-speed and the flood conditions is not yet fully determined. Instead, we use nine scenarios of levee failures. Each scenario describes the structural damages for each cell.

When the economic consequences are calculated in the Consequence module, the wealth transformation function of each agent is consulted. These functions are described in the following sections.

3.1 Wealth transformation function for each Property agent

$$W_{t+1}^{prA}(x,\omega) = W_t + \sum_1^n H_t(x, g_i^t, \omega) + G_t(x, c^t, \omega) -$$

$$D_t(x,\omega) - \sum_1^n (\pi_t(x, g_i^t, \omega)) + I_t(x,\omega) - T_t(x,\omega) - E_t(x,\omega) \quad (1)$$

Let W_1 be the initial amount of wealth of the property agent, given initially as a constant. The wealth is transformed over time as a function on the size of compensation H received from one or more insurer agents i, at time t. The amount of compensation also depends on the coverage g for each insurer agent, where n represents number of insurer agents. Coverage might be a percentage of the property value or a more complicated function with thresholds. Compensation from the local government G is added to the wealth, where c is the compensation level. Cost for damages D on property is deducted. Premiums π are deducted from the wealth according to each insurer agent policy and coverage. The wealth is increased with the income I and decreased with the Catastrophe taxes to the Local Government T and the expenditures E, which contains all other expenses.

3.2 Wealth transformation function for Local government agent

$$W_{t+1}^{Gov}(x,\omega) = W_t + \sum_1^n T_t(x,\omega) - \sum_1^n G_t(x, c_t, \omega) - M(x,\omega) \quad (2)$$

The wealth of the local government is increased by the tax T, received from n property agents. The wealth W is reduced by flood compensation G paid to the property agents, and c is the compensation level. M represents the costs for flood mitigation; cost for maintenance of the three levees.

3.3 Wealth transformation function for each Insurer agent

$$W_{i=1}^{Ins}(x,\omega) = W_t + \sum_1^n \pi_t(x, g_t, \omega) - \sum_1^n H_t(x, g_t, \omega) \quad (3)$$

The initial wealth of the insurer agents, wealth at $t = 1$, is transformed by their income in form of premiums π minus compensation H according to size of coverage g.

4 Policy Simulations

In the simulations, we use nine pre-compiled scenarios of levee failures. For each scenario Vituki Consulting [5], has estimated the pattern of inundation and the amount of economic damages for each cell. We have the following probability distribution for the nine scenarios, also provided by Vituki:

Location.:	1	2	3
100-year flood	0,0012	0,0020	0,0028
150-year flood	0,0012	0,0015	0,0027
1000-year flood	0,00019	0,00033	0,00045

Table 1: Probabilities for flood failures at three locations, from floods of three magnitudes.

The value of the random variable $flood$ is determined in the Monte Carlo module and checked in the Catastrophe module. If it is less than 0.01238 an event has occurred. The variable $flood$ is assigned either the value of the scenario that has occurred according to the scenario distribution, or zero. The geographical information data at hand were at a very fine-grained resolution, the size of each cell measuring $10m^2$, forming a grid of 1551×1551 cells. As the focus of our simulations is to investigate the economical consequences of different financial policy measures, we filtered out all cells that did not contain property and use only the remaining 2508 cells.

Depending on the desired scale of granularity in a model, an agent can represent either an individual or an aggregate. For a realistic modelling of the flood management problem of Upper Tisza, the ideal would be to model each individual property owner as an agent with capabilities to reason and act autonomously and with the ability to communicate with other agents. Our agents lack the ability of communication, however they can reason about the choice to buy insurance or not.

5 Results of the Simulations

We present the results of four policy simulations, where insurance was used as the policy strategy of which the parameters were altered. In the first rounds of simulations, we used the settings described in Table 2. We found that the local government went insolvent at the first flood event, see Figure 3. This indicates that such a policy strategy is very costly for the local government. For the second simulation, we increased the tax level to 10 per

Compensation level from local government	100 per cent of damages
Catastrophe tax level	2 per cent
Number of insurer agents	0
Number of simulations	50×12
Income of property agents	Randomly generated Normal distribution, mean = 33690 Standard deviation 10000)

Table 2: Settings for the first rounds of simulations.

Figure 3: Dynamic wealth of government (tax 2 per cent).

cent, all other parameters stayed the same. We found that even though the government avoided insolvency, some of the property agents became very poor, see Figure 4. We investigated a different approach by introducing two

Figure 4: Property agents go bankrupt.

insurer agents the next simulation. Tax level was lowered to 2 per cent, and compensation level from the local government was reduced to 40 per cent. The coverage level of the insurers was set to 70 per cent of the property value. The assumption that all property agents would buy insurance was made. Premium size was set to 3 per cent of covered property value.

The overall results from this policy simulation looked good. However, the assumption made is not realistic. In Hungary only 40 per cent of the house owners buy insurance. Therefore, we performed a last round of simulations where property agents were given the choice of buying insurance or not.

The decision function $DF = N+AW+H+RW$ consisted of the following four parts:

1. N (neighbours): A function of the number of neighbours (the four closest), who have insurance
   0 returns - 5, 1 returns - 3, 2 returns 0, 3 returns 3, and 4 returns 5.
   Range: [-5 , -3 , 0 , 3 , 5]

2. AW (available wealth): Returns 1 if current wealth minus premium ≥ 0
   otherwise -10 is returned
   Range: [-10 , 1]

3. H (history): Returns -5 if the sum of $flood$ for $cell_i$ from the first round to current round = 0
   (in that case no flood failure has occurred)
   otherwise the sum is returned
   Range: [-5 , 1 ... $9^{CurrRoundNo}$].

4. RW (risk willingness): Returns a random value
   Range: [-5 ... 5]

In the initialisation of this simulation, 40 per cent of the property agents were randomly picked to have insurance. The proportion was chosen as it corresponds to the real situation, as much as 60 per cent of the people in flood risk areas in Hungary has no flood insurance for their homes [6]. All other parameters where unchanged. The decision function was consulted for each property agent for each round (each year) and if the value was 0 or below the agent did not buy insurance.

The results showed that the insurer agents went insolvent after a few events, since the wealth was reduced with the number of property agents who declined the offer. The government stayed solvent, as their wealth was not affected since a large proportion of the responsibility had been transferred to the property agents. On the surface the property agents appeared to be solvent, but when investigating the micro level we found that insolvency did occur, see Figure 5.

Figure 5: Wealth of property agents, when risk-willingness is introduced.

Most vulnerable were the poor property agents in risk-prone location who could not afford insurance. Risk-willing property agents in safe areas, decided not to buy insurance, as history indicated that it was unnecessary. When a rare disaster (scenario 7 or higher) occurred, these property agents were severely affected.

6 Conclusions

When modelling policy problems it is important to take the linkage between the micro and the macro level into consideration. Traditional catastrophe models neglect this aspect, by using aggregates and average values instead of distributions. Our simulations of the flood management problem of the Upper Tisza basin show the need for catastrophe models with the ability to represent agents at different levels of granularity and with the possibility to include social patterns. We have made a first step in this direction by letting the overall outcome be affected by the decisions of the individuals. The individual decision-maker is in turn affected by other agents, forming a social network of decision-makers.

The model is currently being extended and provided with a graphical user interface, in order to use it interactively at a stakeholder workshop.

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