APPLYING THE CONSUMAT MODEL TO FLOOD MANAGEMENT POLICIES

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ABSTRACT

The number and severity of weather related catastrophes is increasing. Economic losses from these catastrophes are escalating, mainly as a result of concentration of assets and population in high-risk areas. How to deal with these economic liabilities in a fair way at the level of the individual property owners is the focus of our research.
As a case study we choose the Tisza, a river in Hungary that flows through one of the poorest agricultural regions of Europe that frequently floods. The use of a simulation model for evaluating alternative flood management policies is a natural choice, since it is impossible to predict the time, location and magnitude of a flood; historical data is of limited use when looking at the outcome of future policies. The behaviour of the river and the financial consequences are simulated on a year-by-year basis.
Here we have extended the simulation model by using the Consumat approach to model the individual property owners. We compare the results with respect to wealth distribution in the case of Consumat agents and simple (non-Consumat) agents. In the Consumat case, the results show that system is more dynamic and more realistic.

INTRODUCTION

There are strong indications that humans are gradually but definitely changing the climate of the earth. Emissions from fossil fuels and greenhouse gasses are altering the atmosphere, leading to an uncertain future of global warming (Jepma and Munasinghe 1998). A possible correlation between the climate change and the frequency and severity of natural disasters can be seen. When the number of catastrophes is increasing financial losses escalate as well. During the period 1988 - 1997 major natural catastrophes cost the worlds economies US$ 700 billion (Munich Reinsurance Company 1998). The raise cannot be explained by the higher frequency of catastrophes alone. An increased concentration of populations and vulnerable assets in high-risk zones is said to be the main reason to the rise of economic damages (Loster 1999). A key problem for policy makers is to identify ways to improve resilience and to protect society effectively against the increasing risk. Questions of accountability and liability for preventing and absorbing the financial losses are on the political agenda in most countries.
Within an international research project (from Austria: IIASA, from Sweden: Department of Computer and Systems Sciences - Stockholm University/KTH, and the Hungarian Academy of Sciences) a case study was performed to identify flood management strategies that were acceptable to the involved stakeholders. The stakeholders involved in the project were the water management bureau's, the insurance companies, the municipalities (represented trough the mayors), catastrophe management organisations, and environmentalist NGO's. To be able to test different flood management policies, a small basin in Hungary was modelled. The initial model was a micro simulation model. To make up for the effect of the individuals living in the area and their decision making, we decided to integrate agents representing the individuals into the simulation model.
For the current article we want to focus upon the distribution of wealth to see if the floods, that only effect part of the basin, has disproportional effects upon the income and wealth of just a few agents. For this we use the Gini coefficient (Gini 1912). As part of the continuous development of the model, we implemented an agent-based model based upon the Consumat approach (Jansen and Jager 1999, Jager 2000). Below we will in more detail describe the case and the Consumat approach. Following this we describe the simulation model. After this we present the simulation results and finally the conclusions and future research are discussed.

THE UPPER TISZA CASE

Hungary is a country where as much as 20 per cent of its 93000 square kilometres of territory are at risk for flooding. The Upper Tisza region is one of the largest, natural riverside systems in Central Europe. Both international and Hungarian studies indicate that floods are becoming higher and more frequent, probably as a result of global warming and land-use changes.
The Tisza is the second largest river in Hungary. The part of the Tisza called Upper Tisza stretches to the county of Szabolcs-Szatmár-Bereg. There is no extensive lake system in the Carpathian Mountains, resulting in a large contrast between the maximum and minimum level of water. The lack of

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lakes is also the explanation to the three annual floods in the Tisza. The first flood occurs in early spring, the second in early summer, and the third in the autumn. Apart from the minor or moderate annual floods, extreme floods occur every 10 – 12 year. During the last years the large floods appear to have become more frequent, large floods occurred in 1970 (levee breaches), 1993, 1995, 1998, 1999, 2000, and 2001 (dike burst).

The basin of study is located in a poor area where the population is dependent on agriculture. Still, the income from agriculture is not sufficient to support the local population. The intention to shift part of the economical responsibility from the government to the individual property owners is a challenging task to accomplish, as most people are too poor to be able to buy insurance. A flood can be very rewarding for those with insurance however; due to current practice of double-compensating the victims, some property owners receive compensation from both government and insurer.

In the flood model, which was used in the Tisza-project, the property owner agents were not modelled as decision-making agents. It was assumed that all property owners who could afford insurance would buy it. The extended model presented here is a first step in the direction of making the model more realistic.

THE CONSUMAT APPROACH

Wander Jager and Marco Jansen (Jansen and Jager 1999, Jager 2000) developed the Consumat approach. It is a model of human behaviour with a focus on consumer behaviour. It combines in an elegant way many of the leading psychological theories, such as theories about human needs, motivational processes, social comparison theory, social learning theory, theory of reasoned action, etc. The theories mentioned all explain parts of human behaviour but lack the generality to take all circumstances into account, thus rendering them less useful for an overall view. To rectify this, Jansen and Jager set out to develop a meta-theory, which in its turn became the Consumat model.

The driving forces at the macro and the micro level determine the environmental setting for the Consumat behaviour. The micro level is formed by the individual Consumats, have needs which may more or less satisfied, have opportunities to consume, and have various abilities to consume the opportunities. Furthermore, Consumats have a certain degree of uncertainty. Depending on the combinations satisfied/not satisfied and certain/uncertain, the Consumats are engaged in four different cognitive processes: repetition, deliberation, imitation and social comparison. When a Consumat is both certain and satisfied, it has no reason to change its behaviour, thus repetition is the strategy chosen. An uncertain but satisfied Consumat has a reason to change its behaviour. In this case the cognitive process chosen is imitation of its neighbours. An unsatisfied but certain Consumat on the other hand will deliberate. The final strategy is to consult the social network, the strategy chosen by uncertain and unsatisfied Consumats.

SIMULATION STUDIES

The flood model simulates levee failures in the Palad–Csecsei basin. A levee failure occurs when a levee breaks, the flood overtops the levee, or when the water finds its way under the levee. The reason for restricting the simulations to levee failures is that insurance companies compensate damages caused by failures, but not damages caused by ground water related floods.

The simulation experiments are used for investigating the effects of various different flood risk management strategies. The flood model has been used in a study about flood mitigation and loss sharing in northeastern Hungary, in the Upper Tisza region (see Brouwers 2002 for a detailed description). Most of the data used in these agent-based social simulations are real data from the Palad-Csecsei basin; in some cases real data were not available (e.g., a geographically explicit income distribution) in which case we used fictive but realistic data.

The Palad-Csecsei basin is geographically represented in form of a grid, in which every cell represents an area of 10 square meters. There are 1551*1551 cells in the grid. Only private properties are considered in these experiments, so all other cells are filtered out. The financial damages are calculated for each inundated cell. The losses for an individual property owner depend on the prevailing loss-sharing policies. In some countries the government compensates the victims to 100 per cent, while other countries are more restrictive. In addition, the property owner can buy flood insurance.

Description of Simulation Model

The area of investigation, the pilot basin, is protected from flooding by levees. Unfortunately, these levees do not offer full protection, they can fail. In the computer model, these events of levee failures are simulated. The probabilities for failures and the estimation of land that is inundated as a consequence are calculated by the Hungarian water consult VITUKI (1999). The model simulates three locations for possible failures are considered and floods of three magnitudes are included (100-year, 150-year, and 1000-year floods). This corresponds to nine levee failure scenarios plus one scenario in which the levee does not fail and no flooding occurs. This tenth scenario, when no flooding occurs, is by far the most common.

Conceptually, the flood simulation model consists of six

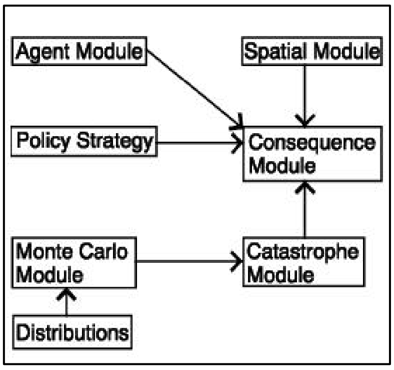

Figure 1 Simulation Model

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modules: the Monte Carlo module, the catastrophe module, the spatial module, the consequence module, the agent module, and the policy module (see figure 1). One round in the model corresponds to one real year (twelve months). A simulation consists of 30 rounds (years).

For each year that is simulated, it is first decided in the Monte Carlo module whether a levee failure occurs or not. If a failure occurs, the catastrophe module contains the damage functions that estimate which land areas are flooded. This information is mapped against geographic data in the spatial module, pointing out which properties are affected by the levee failure. The consequence module presents the economical consequences for each flooded house, to calculate the financial outcome, the policy module is consulted to see how much insurance coverage the property holds, and to what extent the government compensates flood victims. For each simulated round (year), the financial status is updated for all parties: the individual property owners, the insurance company, and the government, this is handled in the agent module.

Implementation

The model was programmed in Matlab, with all the entities internally represented in vector format. This made it possible to use Matlab-specific commands, making simulations quite fast and efficient. The results could easily be presented graphically within the Matlab environment, offering straightforward analysis the simulations. During the development process this allowed for fast, interactive testing of the effects of changes in the model settings. A simulation run, i.e. 30 years, takes approximately one minute on an average personal computer.

Description of Agent Decision Making Model

As described above, we have two different types of agents that we compare. The first type of agents have a simple decision making model. This means that if an agent has enough financial means to buy insurance, it does. The second type of agents is based upon the Consumat approach described above. Thus agents have the following alternatives:

1. Agent is satisfied and certain: Repetition

2. Agent is satisfied but uncertain: Imitate neighbours (if more than 2 neighbours are insured, the agent will also buy insurance)

3. Agent is not satisfied but is certain on flood risk: Deliberate (change strategy if the agent can afford to buy insurance)

4. Agent is not satisfied and is uncertain on flood risk: Imitates Social Network (goes with the majority in its network).

Agent satisfaction is coupled to the financial means an agent has. An agent is satisfied if its wealth is larger than the agent's satisfaction threshold and if its wealth is larger than last year. The uncertainty of an agent is coupled to its risk profile and the number of years that has passed since the last flood failure occurred. The agents are part of a social network. In this network, some agents are assumed to be trend-setters, the decisions made by these agents have a large impact on other agents' decisions. These trend-setters are the Social Nodes. The Social Nodes are connected to more agents than a "normalagent", thus their decisions will affect more agents.

In the section on simulation set-up all functions are specified.

Simulation Set-ups

General Settings

- Income = random distribution with mean 36 900 * 12
- Flood frequency = 4

  As statistical records do not reflect last decades' increased flooding, the return period for floods has been decreased. Flood frequency 4 means that the probability for a 100-year flood to occur is: 1/100 * 4
- Premium size for insurance = 0.02 per cent of the property value

  The size of the insurance premium does not reflect the underlying flood-risk; it is based on the property value alone. This corresponds with existing premium prizing in Hungary
- Penetration rate = 0.6

  The fraction of property owners who carry flood insurance (bundled with property insurance). The average penetration rate for property insurance in Hungary is 60 per cent
- Expenses = 0.9

  The figure 0.9 is just estimation, however, the area that is simulated is a very poor area. Thus 90 percent of an agents year income is spend on direct expenses.
- Content Threshold = 10000 HUF (Hungarian Forints)

  This figure corresponds roughly to 1/3 of a monthly income, an agent who has less money to spend (for an entire year) is not content
- Flood Compensation from Government = 0.5
- Flood Compensation from Insurer = 0.8

  For the property owners with insurance contract, the insurance companies compensate a fraction of the damages. The size of the fraction can be decided by using different coverage, or deductibles. For simplicity, we are assuming that the companies deduct 20 per cent of the damages and only compensate to 80 per cent

Social Settings

- Minimum number of contacts in social network = 2
- Maximum number of contacts in social network = 50
- Number of Social Nodes = 10
- Probability for a property owner to know a social node = 0.9

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- Number of neighbours = 5

Simulation Settings

- Time period that is simulated = 30 years
- Number of property owner agents = 2580
- Series of simulations = 2
- One series of 9 * 30 years with Consumat model for decision making on insurance
- One series of 5 * 30 years with simple model for decision making on insurance
- Wealth transformation function for property agents (an agent can not have a negative wealth in these experiments)
  - No flood failure occurred this year:
    Wealth year n = max (0, Wealth year n –1 + Income * (1-expenses) – Insurance premiums)
  - A Flood failure did occur this year:
    Wealth year n = max (0, Wealth year n –1 + Income * (1-expenses) – Insurance premiums – Flood Damages + Gov Compensation + Insurance Compensation)
- Risk function
  - Risk for flooding = RiskValue - log2 (Number of years since last flood)

  If the risk is higher than zero, a flood is expected. The risk values are randomly distributed between zero and five. A risk value of zero means that the agent will never expect a flood since the risk function is always below zero. A risk value of 5 means the agent will always expect a flood even if it has not occurred within the last 30 years (which is the maximum number of years in the simulation).

The Gini coefficient

A common way to express the distribution of wealth or income is to analyse the relationship between population and share of income. One of the first to depict this relationship graphically was Lorenz (1905). The Lorenz curve displays the relationship between cumulative percentage of population (X-axis) and cumulative percentage of income or wealth (Y-axis). A diagonal line with a 45 degrees slope thus represents a totally equal distribution. The deviation from this line is a measure of the inequality of the wealth distribution.
Gini (1912) developed a mathematical measure for this deviation by calculating the area between the Lorenz curve and the line of perfect equality in ratio to the area below the 45-degree line. A Gini index of 1 denotes complete equality, a Gini index of 0 complete inequality. The Gini coefficient is the most used measure for distribution inequality used by e.g., the World Bank Institute.
We used the Gini coefficient to analyse the results of the different simulation settings with respect to the distribution of wealth within the agent population. Since we do not have the corresponding data for the real population, we are only interested in trends.

SIMULATION RESULTS

The simulations were run only a couple of times to obtain a feeling for the possible results. The base model, where agents buy insurance when they can afford it proved to produce a rather static society. Less and less agents bought insurance since most of the uncertain agents were those who suffered from floods while their neighbours did not and most of time did not buy any insurance. The results for the five runs of this model are depicted in figure 2.

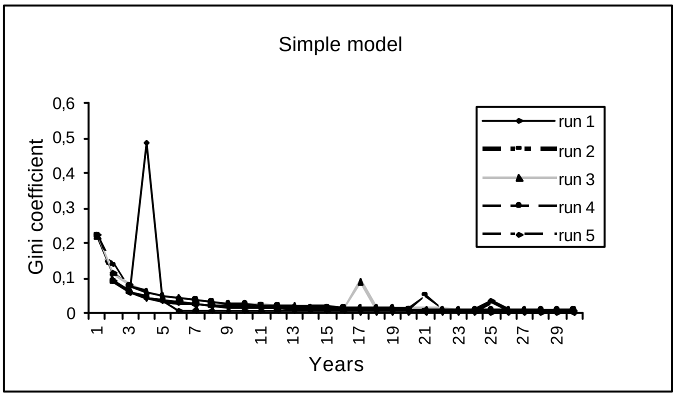

Figure 2 Gini Coefficient for the Base Case Simulations

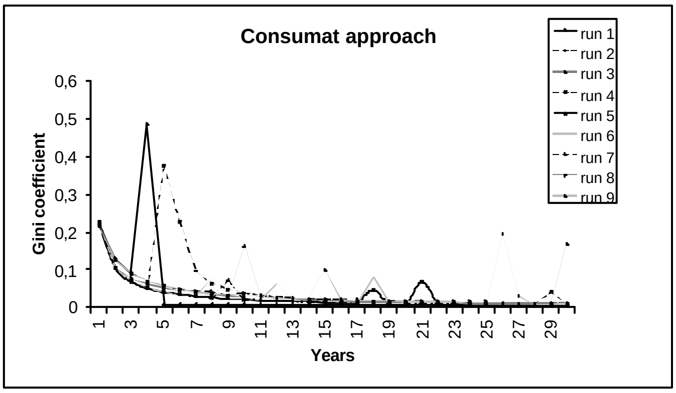

Figure 3 Gini Coefficient for the Consumat-Based Simulations

The Consumat based simulations on the other hand show a more dynamic, one might even say chaotic society. Most floods resulted in changes in insurance buying behaviour and in a skewer wealth distribution. The results are depicted in figure 3.
At the level of the individual simulation run, we can look at the details. We choose to analyse run 9 of the Consumat-based model since in this run, several floods occurred. In figure 4, the first graph depicts the amount of insured agents, whereas in the second graph the floods are shown. The first flooding causes an increase in the amount of insured agents, as expected. The second flooding however, results in fewer insurance takers. Even the last two floods have this effect.
Figure 5 depicts the amount of agents following a certain Consumat strategy. As expected, the agents repeat their initial decision making model until a flooding occurs. The first flooding causes most agents that are effected to imitate their neighbours' behaviour, while some reconsider their strategy.

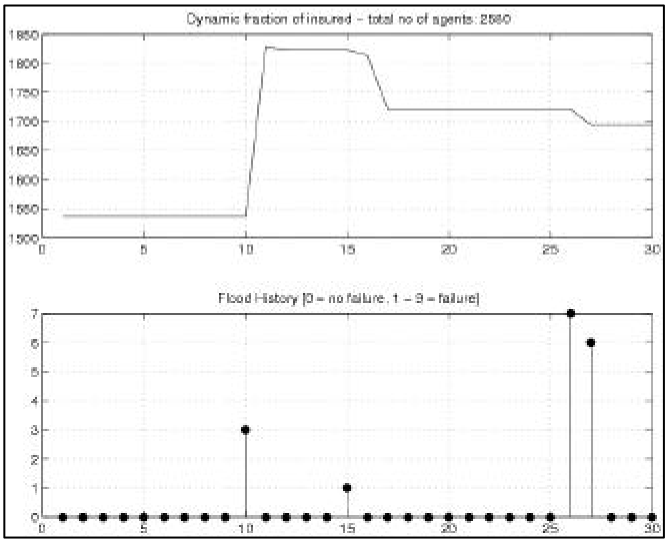

Figure 4 Results of Simulation Run 9 - Insurance Rate and Floods

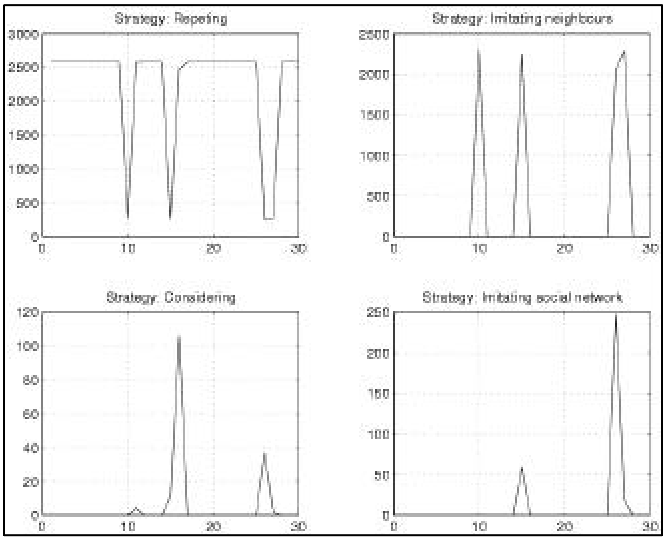

Figure 5 Results of Simu lation Run 9 - Agent Strategies

The second flooding shows more agents reconsidering their strategy, with another large portion of agents imitating neighbours and a small amount of agents imitating their social network. The last strategy is more prominent in the case of the last two floods (since these occur back to back, they can not be distinguished in the results).

The decrease in insurance buyers after a flood may be explained by a lack of funds due to insufficient insurance. The order of the strategies the agents choose is also easily explained. At first, all agents are satisfied and confident, thus they choose to repeat their choices. After the first flood, the agents are mostly still satisfied but are uncertain since they did not predict the flood. Thus they imitate their neighbours. A small portion is unsatisfied but managed to predict the flood, thus they deliberate. The second flood causes again a large amount of strategy change due to imitation of neighbours, followed a year later by deliberation. The third flood also causes imitation but in this case followed by imitation of the social network and not so much by deliberation. In the case of the second flood, the agents thus go from uncertain but satisfied to certain but not satisfied, while in the case of the third and fourth flood, agents go from satisfied and certain to satisfied and uncertain and after this proceed to unsatisfied and uncertain.

DISCUSSION AND FUTURE RESEARCH

The extension of the model has proven successful, since the results are more in line to the real world. Even if the Gini coefficient values are not in the range usually found in a whole society, in our case most inhabitants are very poor and have about the same amount of money to spend. We plan to further investigate these by on the one hand approach insurance companies to try and get access to their statistics, and on the other hand by interviewing a representative selection of the inhabitants in the studied basin to investigate their social network and decision making procedures.

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REFERENCES

Brouwers, L. 2002. “Flood Risk Management Policy from an Insurance Perspective.” Ph.L. thesis, Department of System and Computer Sciences, The Royal Institute of Technology and Stockholm University, Sweden.

Brouwers, L. 2003. “Spatial and Dynamic Modelling of Flood Management Policies in the Upper Tisza”, Interim Report IR-03-02, IIASA, Austria.

Gini, C. 1912. *Variabilitá e Mutabilita.* Bologna, Italy.

Jager, W. 2000. *Modelling Consumer Behaviour.* Ph.D. thesis, Universal Press, Veenendaal, Holland.

Janssen, M.A. and W. Jager. 1999, “An Integrated Approach to Simulating Behavioural Processes: A Case Study of the Lock-in of Consumption Patterns.” *Journal of Artificial Societies and Social Simulation*, 2, No. 2. Available online at http://www.soc.surrey.ac.uk/JASSS/2/2/2.html.

Jepma, C. J. and M. Munasinghe. 1998. *Climate Change Policy.* Cambridge University Press, Cambridge.

Loster, T. 1999. “Flood Trends and Global Change”. In *Proceedings of the IIASA Conference on Global Change and Catastrophe Management: Flood Risks in Europe*, International Institute of Applied Systems Analysis, Austria.

Lorenz, M.C. 1905. “Methods of measuring the concentration of wealth”. *Journal of the American Statistical Association.* 9 209-219.

Munich Reinsurance Company. 1998. “Annual Review of Natural Catastrophes 1997”. Technical report, Munich Reinsurance Company, Munich, Germany.

Vituki Consult Rt. 1999. *Explanation of Detailed Methodology for Flood Damage Assessment*, Hungary.

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