Microeconomic Motives of Land Use Change in Coastal Zone Area: Agent Based Modelling Approach

Tatiana Filatova, Anne van der Veen
Department of Water Engineering and Management
University of Twente
E-mail: T.Filatova@ctw.utwente.nl

Abstract: Economic growth causes growing urbanization, extension of tourist sector, infrastructure and change of natural landscape. These processes of land use change attract even more attention if they take place in coastal zone area. In that case not only the efficient allocation and preservation of natural area, but also reduction of potential damage from flooding is important. Driven forces of land use at macro and micro levels should be taken into account. This paper presents an agent based model (ABM), which is designed to simulate land use change in coastal zone area based of human behaviour. The aim is to understand motives, types of connections and interactions between different actors and natural environment in order to get a feeling how different policy options and natural conditions might affect land use configuration. Microeconomic motives of land use decisions are in the focus of the research. Individual land use decisions are guided by economic and geomorphologic conditions, spatial planning and coastal protection policy. Each location choice is done according to a set of defined rules and land attributes. Space is represented as a grid of cells. Self-interested economic agents interact with each other trying to benefit from a certain type of land-use. We introduce the perception of risk of flooding in the model of land use as an innovative aspect of ABM simulations for water management problems. Based on decisions of spatially distributed individual economic agents operating in a policy framework, the model produces aggregated land-use patterns as an outcome. Understanding the factors that affect land use decisions will help policy makers design incentives to achieve policy objectives in coastal zone area. The proposed ABM will be applied to a study area in the province of North Holland in the Netherlands.

Keywords: Spatial modelling; risk perception; agents

1. INTRODUCTION

Land use change is a result of interactions between economic and natural systems, which are characterized by nonlinearity, cross-scale interactions and emergent properties. Tourism development, urban development, commercial infrastructure, agriculture and natural area compete for a limited space. The continued economic growth and increase of population cause expansion of urban area, which constrains space available for other functions. Growing urbanization negatively impacts the flexibility of an area, leaving less room for adjustments. In coastal zone area (CZA) the issue of space allocation is even more essential because of the potential risk of damage from flood and erosion. Control of land use configuration here is especially important in order not only to preserve natural areas but also to reduce the damage. In the Netherlands a quarter of its surface area is below sea level. For different part of the coast Dutch coastal zone management policy (CZMP) defines probability of flood ranging from once in every 1250 years to once in every 10000 years. It depends on the morphological conditions (availability and spatial distribution of sand) and on the economic value of protected territory. These factors imply that CZMP and spatial planning policy (SPP) in the Netherlands are strictly defined and regulated at macro-level. However, in spite of tough planning the real world land use decisions, which are done by individuals, may facilitate undesirable spatial developments. In the report of Rijkswaterstaat [2005] part of urban and rural area of the Netherlands is beyond the legally protected line and increasing urban area constrains future efforts to reinforce the sea defences. Risk, defined as a probability of event multiplied by damage, is the main instrument and criteria, which leads CZMP and should provide safe and efficient land use configuration. At the same time the question of risk communication, perception and ways to influence it by policy instruments is still open (see Balfoort et al. [2002]). In order to predict land use developments in the context of different scenarios of CZMP and avoid negative consequences a better understanding of motives individual spatial behaviour is needed. We propose a model, which simulates the emergence of land use patterns, as a result of micro decisions.

Several simulation models of land use change (Veldkamp and Fresco [1996], Engelen et al. [2003]) and management of coastal zone areas (De Kok et al. [2001]) were elaborated. These models are comprehensive in many aspects and help understand the ecological nature of the processes, but do not monitor microeconomic forces of land use change (such as human behaviour and interactions). The well developed research on spatially-explicit micro-economic modelling is presented by Bell and Irwin [2002]. Some of foundations proposed there helped us to elaborate our model, but their model does not intend to take into account special conditions of CZA, which are essential in our case. There is a number of spatially explicit agent-based models available (Barreteau et al. [2004], Grelot et al. [2005]), but they mainly simulate river basin management processes.

What are the drivers of land use change in the level of individual economic agents? To what internal motives is the outcome of land use decision most sensitive? How land use patterns emerge out of many individual decisions? How do stakeholders percept risk and how risk issue can be communicated? How policy regulations can influence the decision-making process? In order to answer these questions it is important to include micro-level human component in the spatial land use simulation. ABM (Gilbert and Troitzsch [2005]) was chosen as a method of spatially explicit microeconomic modelling of land use change. ABM gives a wide range of possibilities for land use modelling (Parker et al. [2002]) as well as for emergence of aggregated patterns from economic behaviour (Tesfatsion [2006]) which we emphasize. ABM in particular brings in the economic actor into the development and analysis of spatial scenarios (Bousquet and Le Page [2004; Ligtenberg et al. [2004]).

The focus of the ABM model, which we propose, is to simulate process of land use decisions and emergence of patterns in coastal zone area taking into account the real situation in the Netherlands. The individual land use decisions and policy framework we model are empirically grounded in processes occurring in the Dutch province of North Holland. The real world data based on statistical information, data from governmental agencies and surveys will be used for validation.

2. CONCEPTUAL MODEL

In order to understand driving forces of individual land use decisions and further development of urban area in CZA we apply bottom-up approach. Individual agents try to optimise their wellbeing (maximise profit and utility) within the rules defined by a certain policy framework. Behaviour of economic agents is determined by *internal* characteristics such as goals and behavioural rules (profit maximisation, flood risk perception). *External* factors are the boundary conditions defined in the level of a country or a province by policy makers. They include CZMP, SPP and economic policy.

Many individual land use decisions distributed across space provide new patterns of land use as an aggregated outcome. Different patterns in land-use result in different social and economic outcomes. They define what will be the value added produced, the level of unemployment, as well as negative effects on the ecosystem. The damage, which might be caused by flood or erosion, depends on the spatial distribution of land use activities. Usually it is comparatively high for the urban area (partly because monetary damage to environment is not easy to calculate and quite often it is underestimated). Risk of natural hazard is defined as probability of hazard multiplied by the expected loss in the area endangered (Balfoort et al. [2002]).

As a result of land-use change some areas along the coast may require more protection because of their high economic value. The risk of natural hazard is used as one of the indicators for optimization of decision-making in Dutch CZMP nowadays. It may cause changes in the coastal protection, spatial planning and economic policy in the macro-level. New policy regulations influence both internal and external factors of individual behaviour, which give rise to a new circle over the scheme.

The model defines two types of actors: "land user" (LU) and "governmental authority" (GA). The model mimics agents who define new location or change the type of activity taking into consideration risk of flooding. Allocation decision is based on the individual goals and types of behaviour of various actors. Many spatially disaggregated decisions of various agents form the new land use configuration and consequently new potential damage to the territory under risk of flooding. We suppose that each location choice is done according to:

- goal of an agent;
- set of defined behavioural rules;
- land attributes and environmental conditions;
- outcome which agent gets from the decision

LU agents can implement several types of activities, such as agriculture, tourism or urban area. GA agent is interested in maintaining economic activity on its territory (to have investments from land users). However to reach this goal he should implement flood defences (with a certain probability of flood) and provide options for insurance from flooding which will be of interest for LU agents. LU agents express their demand in space in coastal zone area and want to have a certain level of safety of their investments. Both types of actors have the common goal to sustain such level of risk of flooding, which is acceptable by all involved actors. According to the land use configuration at the end of each period the damage from flooding can be defined as well as the amount of insurance, which should be paid by one of the parties.

Agents take information from the spatial environment. Based on the goal, information from the environment and behaviour rules agents make decisions concerning land use type or policy regulation, which are implemented in the spatial environment. GA and LU agents are also interacting with each other and are directly involved in shaping the land use. Figure 1 presents a conceptual framework for simulation of emergence of land use patterns by means of agent-based modelling.

Space is represented as a grid of cells (parcels). It is the scarce good in coastal zone area. So, a cell under a certain land use type cannot be used for anything else over a particular time period.

Time step of the model simulation is one year. Each time step LU agents analyse the situation in the spatial and regulatory environment. Depending on their budget, past experience, level of risk perception and real possible risk, insurance scheme and spatial plans of GA agent LU agents invest in a certain cell.

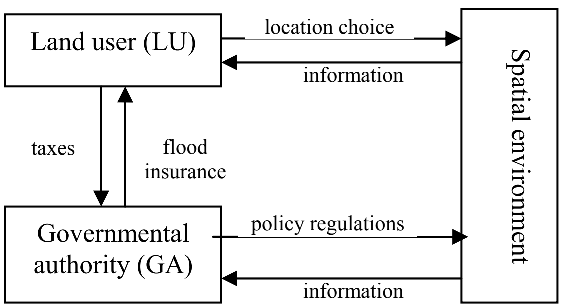

Figure 1: Conceptual framework of agent-based model of land use

Simulation includes several scenarios of CZMP (position of the safety line, strengths of dunes/dykes in terms of probability of flood), optional schemes of insurance from flooding and level of individual risk perception. The data about policy options is taken from the Dutch policy regulations (Balfoort et al. [2002]; Rijkswaterstaat [2005]). Data about individual risk perception will be extracted from a survey by Terpstra and Gutteling [2006]. Real world data about the situation in the Netherlands will be used to perform sensitivity analysis. A map of land use patterns in the study area of the coastal zone with information about potential damage is supposed to be an outcome of the simulations.

3. AGENT DESCRIPTION

3.1 "Land User" Agent

In the process of simulation self-interested economic agents interact with each other trying to benefit from a certain type of land-use. Three types of land use activities are assumed: agriculture, tourism and urban area. Actually, LU agents represent main stakeholders in coastal zone area. The location choices of LU agents are based on a set of rules and land attributes as in the research by Parker et al. [2002; Bousquet and Le Page [2004] and are driven by profit maximisation as described by Fujita and Thisse [2002]. In addition to that the decision strategies of land users are elaborated during the discussions with specialists from National Institute for Coastal and Marine Management. Besides, we are planning role-playing games where participants represent main stakeholders. It will clarify the formalism used for the behaviour rules.

LU agents decide what activity to implement on a particular spatial cell that they own or to which location to move if it maximises their expected returns in spite of concomitant costs. Each type of land use (tourism, agriculture and urban) has its own profit function, i.e. function of financial returns from a unit of investments.

In the first stage of simulations, LU agents start with a given capital. The profit, which they earn during one simulation step, can be reinvested in the next step. Each time step LU agents may choose one out of the set of actions:

- to maintain the same type of activity in the same parcel,
- to change type of activity in the current cell,
- to move to another cell and proceed with the same activity,
- or to sell the parcel and leave land-use decision process in the next stage.

The decisions of LU agents are based on the comparison of potential profit from one of the activities listed above. As described by Bell and Irwin [2002] the change of land use type will occur only if expected returns from converted cell minus costs of transition are greater than returns from the cell without change.

We incorporate a *perception of risk of flooding as an innovative elem*ent in a model of land use behaviour. CZMP in the Netherlands assumes that different areas of coastal zone have different levels of safety depending on the economic value of the territory. The safety level of dunes and dykes along the coast ranges from the probability of flood of once in 1250 years to once in 10 000 years.

Besides this objective factor, we assume that individuals have their subjective perceptions of the situation. Individual perception of risk depends very much on the previous experience and communication about flood risk from the governmental authority as it was shown by Terpstra and Gutteling [2006]. Nowadays, the Dutch Governmental authorities initiate elaboration of insurance schemes against flood damage (see Rijkswaterstaat [2005]), which also have influence on the perception of risk. We will focus on these insurance frameworks in the sections about GA agent.

Level of risk perception and its influence on the agent location behaviour may differ:

a) people accept relatively high probability of flooding and buy insurance to protect their property against the risks in this area;
b) people accept high probability and avoid much investment in building and infrastructure, instead investing in adaptive and flexible activity;
c) people would rather invest in an area with low probability of flooding;
d) or people are not aware of flood risk.

Each LU agent has a certain level of risk perception, which influences their final decision about land use activity according to the following algorithm:

1. LU agents calculate their expected profit from potential activities
2. LU agents calculate expected damage form flood with a certain probability of occurrence
3. According to the level of risk perception LU agents adjust their expected profit from each potential activity
4. Following the scheme of insurance against flooding, which is proposed by GA agent, LU agents calculate their costs and benefits from the activity in a certain area
5. While comparing all possible scenarios of their activities, LU agent choose the one, which maximises their profit under budget constrains.

Following Grelot et al. [2005] a LU agents while choosing a location besides profit maximisation strategy might have mimetic or random behaviour. At the end of each time step, LU agents pay taxes to the budget of GA agent.

3.2 "Governmental authority" Agent

The aim of the GA agent is to maintain economic development on his territory. He is interested in attracting LU agents who make investments and pay taxes. To have LU agents on his territory GA agent should provide a certain safety level of the area and/or an attractive scheme of insurance against flooding. At the same time, it is important for GA agent to maintain economic development within the boundaries of spatial planning plans imposed by the Netherlands Ministry of Housing, Spatial Planning and the Environment. GA agent provides policy regulations on the territory under his control and does not participate directly in the land use activity.

The pressure on the available space increases in the Dutch coastal urban areas. Government has defined the so-called safety line. The territory behind this is considered legally protected. Contrary to buildings and infrastructure behind the flood defences, buildings on or in front of the flood defences have no legal protection level with respect to coastal erosion or flooding as it is shown Balfoort et al. [2002]. The local government is legally responsible for informing the public about the risks. However, in practice communication on this issue is not efficient. As a result there are unprotected areas of coastal towns where reconstruction of existing buildings and construction of new ones is possible. In case of the flood damage it is likely that the public will apply to the government for compensation.

In order to find a solution for risk management of the area of coast under risk, four policy options were formulated in Rijkswaterstaat [2005]. These scenarios were taken as a basis for the behaviour of a GA agent in the simulation model. Thus, GA agent can propose one of the following options for flood insurance on his territory:

A. LU agents take the risk on their own, GA agent continues the policy of maintaining the coastline with no additional construction;
B. GA agent keeps the present safety levels and provides risk-aware construction, LU agents insure their property at a reasonable rate, which is defined by GA agent;
C. GA agent takes responsibility for damage and may either offer inhabitants a certain level of insurance or may enforce building restrictions; LU agents partly take risk on their own;

D. GA agent includes unprotected area within the chain of flood defences and guaranties the same level of protection as for legally protected area, extra flood defences are built, the property of LU agents is under insurance.

Nowadays, insurance against flood in the Netherlands is under consideration and is not implemented yet.

Summarizing, interactions between GA and LU agents during simulation include the communication of the following information:

- GA agent has power to define safety lines, spatial planning policy and insurance schemes,
- LU agents have a power to define the type of activity, type of behaviour, have perception of risk and decide whether to take risk of damage within the framework of conditions defined in the insurance policy.

4. SPATIAL ENVIRONMENT

Spatial environment proposed in the simulation model is part of the coastal zone area. Space is represented as a grid of cells. Each spatial cell is heterogeneous in terms of limitations applied by the morphological system (probability for land to be destroyed), coastal protection and spatial planning policy and economic conditions attached to the area, as well as natural conditions (soil type, etc.). In other words, the environment represents the boundary macro conditions in which agents act. Attributes of each cell in spatial grid make it available for a certain type of land use. Interpolation of these conditions defines the supply space for a certain land use type.

Spatial environment of the ABM combines several features:

- the information on flood/erosion risk (probability of risk),
- CZMP map (including scheme of insurance from flooding),
- administrative (tax, rent),
- spatial planning maps

These features serve as initial conditions for the decision making process of LU agents. Parameterisation of these factors gives the possibility to run scenarios for changing probability of natural hazard or spatial planning strategy.

During the process of simulation both GA agent and LU agents exchange information with the spatial environment as presented in the Figure 1. LU agents observe the information about safety line position, spatial planning maps, etc., attached to each cell they are interested in. Outcome of the process of land use decision of LU agents (location choice) is recorded in particular cells/parcel of the spatial environment. At the end of each time step LU agents get the expected returns from each parcel.

For each cell the GA agent gives the values of each of the features mentioned in the list above. As a feedback flow he receives data about location choices of the LU agents. Depending on the position of cells relatively to the safety line, GA agent can calculate what will be the damage for the territory under his authority in the case of flood.

Interactions between agents and spatial environment provide spatially explicit simulation of land use decisions and emergence of patterns.

5. CASE STUDY

Case study area is the province of North Holland. Two coastal cities (Bergen aan Zee and Egmond aan Zee) are of great interest. There are several risk areas along the coast defined where a significant part of some coastal cities is located outside the safety line (see Figure 2).

Figure 2: Safety lines for the town Bergen aan Zee, Netherlands

The area, which is on or in front of the flood defences (marked as a black line here - Kernzone), has no legal protection level with respect to coastal erosion or flooding. Moreover, the position of this line is dynamic (point-line indicates the predicted future position – Beschermings zone) and is shifting landward. Thus, the questions are what is the appropriate way to reorganise this territory (negotiate for a higher safety level or to change land use configuration) and how will it influence spatial behaviour of land-users.

6. CONCLUSIONS

An agent-based model, which simulates the process of individual land use decision-making process in coastal zone, is proposed. The location of economic activities matters a lot because it provokes external effects from clustering and influences the risk of flooding. An important innovative aspect is that we incorporate perception of risk of flooding in the model of individual land user.

The proposed ABM is elaborated to simulate land use decision process empirically grounded in the real world situation in the Netherlands. An iterated exchange between designed and empirical models helps to show the complex dynamics of economic system developing within the natural boundaries of CZA. The advantage of ABM approach is that it includes the human behaviour component in the model of land use change. Based on the decisions of spatially distributed individual economic agents operating in a framework of a certain coastal zone management policy, the model produces aggregated land-use patterns as an outcome. Understanding the factors that affect land use decisions will help policy makers design incentives to achieve policy objectives in coastal zone area.

ACKNOWLEDGEMENTS

The authors are grateful to the National Institute for Coastal and Marine Management (RIKZ) and especially to Jan Mulder for valuable advices and information provided.

REFERENCES

Balfoort, H., A. Arends, H. Erenstein and E. v. Huijssteeden *Towards an Integrated Coastal Zone Policy*. The Hague, Direct Dutch Publications BV (2002).

Barreteau, O., F. Bousquet, C. Millier and J. Weber "Suitability of Multi-Agent Simulations to study irrigated system viability: application to case studies in the Senegal River Valley." *Agricultural Systems*(80): 255-275 (2004).

Bell, K. O. and E. G. Irwin "Spatially explicit micro-level modelling of land use change at the rural–urban interface." *Agricultural Economics*(27): 217-232 (2002).

Bousquet, F. and C. Le Page "Multi-agent simulations and ecosystem management: a review." *Ecological Modelling*(176): 313–332 (2004).

De Kok, J.-L., G. Engelen, R. White and H. G. Wind "Modeling land-use change in a decision-support system for coastal-zone management." *Environmental Modeling and Assessment*(6): 123-132 (2001).

Engelen, G., R. White and T. De Nijs "Environment Explorer: Spatial Support System for the Integrated Assessment of Socio-Economic and Environmental Policies in the Netherlands." *Integrated Assessment*(4): 97-105 (2003).

Fujita, M. and J.-F. Thisse *Economics of agglomeration. Cities, industrial location and regional growth*, Cambridge University Press (2002).

Gilbert, N. and K. G. Troitzsch *Simulation for the social scientist. Second edition.* Glasgow, Open University Press (2005).

Grelot, F., O. Barreteau and B. Guillaume. *SIGECORIS: An Agent based Simulator to explore collective flood management options*. Agent-Based Models for Economic Policy Design, Bielefeld, Germany, ZIF, University of Bielefeld (2005).

Ligtenberg, A., M. Wachowicz, A. K. Bregt, A. Beulens and D. L. Kettenis "A design and application of a multi-agent system for simulation of multi-actor spatial planning." *Journal of Environmental Management*(72): 43-55 (2004).

Parker, D. C., T. Berger and S. M. Manson. *Agent-Based Models of Land-Use and Land-Cover Change.* LUCC Report Series No. 6; Report and Review of an International Workshop, October 4-7, 2001, USA, University of California (2002).

Rijkswaterstaat. Hoofdrichtingen voor risicobeheersing in kustplaatsen. Den Haag (2005).

Terpstra, T. and J. M. Gutteling. The public perception of flooding and flood risk. The effect of group discussions on risk perceptions. Enschede, Final Report of Interreg IIIb FLOWS Work Package 2D (2006).

Tesfatsion, L. Agent-based computational economics: a constructive approach to economic theory. *Handbook of Computational Economics Volume 2: Agent-Based Computational Economics*. K. L. Judd and L. Tesfatsion, North Holland (2006).

Veldkamp, A. and L. O. Fresco "CLUE: A Conceptual Model to Study the Conversion of Land Use and Its Effects." *Ecological Modelling* (85): 253-270 (1996).