Modelling and simulation of tourist land uses through a multiagent system

Antoine Belgodere
University of Corsica
belgodere@univ-corse.fr

Alexandre Muzy
University of Corsica
amuzy@univ-corse.fr

Eric Innocenti
University of Corsica
innocenti@univ-corse.fr

Sauveur Giannoni
University of Corsica
giannoni@univ-corse.fr

Abstract— **The aim of this paper is to study the optimal allocation of land between tourism and agricultural activities. In order to achieve this objective, an original method is implemented using both standard tools of economics and multiagents system simulation tools. The whole approach constitutes an original transdisciplinary tool for the exploration of virtual experiments.**

I. Introduction

Ioannou (2002) or even Peña & al. (2005) showed that tourism development may deeply modify the scheme of land use. As a matter of fact, tourism is a land-intensive sector [1]. It induces that an economy willing to develop tourism has to allocate, or even transfer, parts of its land endowment toward the tourist industry. Furthermore, environmental amenities associated with agriculture also act as an attractiveness factor for tourists. In this context, the economy has to operate an optimal trade-off between tourism and other activities. Rey-Maquieira Palmer & al. (2005) already explored this trade-off and put into light that if agents disregard at externalities an amount of land higher than the optimal one will be dedicated to tourism. The aim of this paper is to study the optimal allocation of land between tourism and others activities. In order to achieve this objective, we implement an original method using both standard tools of economics and multiagents system simulation tools. Our approach has to be divided in two steps. The first one consists in building an economic model describing the dynamics of tourist facilities building in an economy divided in N subregions. In fact, we consider that the common objective of agents is to maximize the intertemporal welfare. We assume that welfare positively depends on income generated both by tourist frequentation and by agricultural production. Indeed, in order to account for the environmental effects of tourism development, we consider that the allocation of land to tourism in any sub-region generates a negative external effect. The classical example is the one of a remarkable natural site (e.g., a beach), that is at highly attractive and pleasant but that turns polluted as the number of tourists is increasing[2]. Once this economic model is built, we use a multiagent system in order to simulate the evolution of the allocation of land between both sectors. The next section introduces the economic model, then its implementation in a MAS framework is presented and in a last section we draw the main conclusions and the possible applications.

[1]See for example Nowak & Sahli (2005)

[2]See León & al. (2003)

II. The model

A. Characteristics of the economy

The studied region is divided in N sub-regions, indexed by $i = 1, ..., N$. The area of sub-region i is $\bar{S}_i$. We identify only two kinds of uses of the land: a tourist use, and other uses. For simplicity, we shall call the other uses 'agricultural use', although this category can include housing or industrial uses. At time t, an area $S_i(t)$ is devoted to tourism, whereas $\bar{S}_i - S_i(t)$ is devoted to agriculture. Hereafter, time references will be removed when no confusion is possible. Agricultural activity is assumed to yield a rent r_i by unit of land, in the sub-region i. Thus the income from agriculture in i is $r_i\left(\bar{S}_i - S_i(t)\right)$

The income from tourism industry in sub-region i is:

$$S_i P_i\left(A_i, S_i\right)$$

Where $P_i\left(A_i, S_i\right)$ is the inverse demand function of tourist services.

Notice that P_i must be thought of as an average price. Indeed, we assume that, in each sub-region, the tourist infrastructures are built around a remarquable place (such as a beach, an old castle, a historical center, ...). The first infrastuctures are closed to this place, and are rented to tourists at a greater price than the later, farer infrastructures. A_i is a parameter that denotes the fundamental appealing value of the sub-region i. It means that, *ceteris paribus*, a sub-region with a hight A attracts more tourists than a sub-region with a low A. $P_i(.)$ exhibits the following properties:

$$\frac{\partial P_i(A_i,S_i)}{\partial A_i} > 0, \frac{\partial^2 P_i(A_i,S_i)}{\partial A_i^2} \leq 0$$

$$\frac{\partial P_i(A_i,S_i)}{\partial S_i} < 0, \frac{\partial^2 P_i(A_i,S_i)}{\partial S_i^2} \leq 0$$

The higher appealing value, the higher price, the higher sub-regional tourist lands, the lower price. The latter effect reflects both the *distance from the remarquable place* effect and the congestion effect at the sub-regional level:

- As new infrastructures are built, the average distance from the remarquable place of the sub-region increases, and

then the average willingness to pay for the tourist services deacreases.
- The tourism specialization relies on the availability of some natural or cultural imperfect public goods, such as beaches, hoods, or heritage sites. The sub-regional congestion effect makes these public goods imperfect ones.

The area dedicated to touristic infrastructures evolves according to the following differential equation:

$$\dot{S}_i = B_i - \delta S_i \quad (1)$$

Where $B_i \geq 0$ is the rate of building of new tourist infrastructures (hotels, restaurants, shops,...), and δ is the rate of depreciation of these infrastructures. The infrastructures are built at a cost $C(B_i)$, with $C'(B_i) > 0, C''(B_i) > 0$.

Finally, we assume that the tourist infrastructures, by altering the environment, cause a regional negative externality $E(S)$, with $E'(S) > 0, E''(S) > 0$ where $S \equiv \sum_{i=1}^{N} S_i$ is the aggregate regional tourist area. This is one way among others to couple the different sub-regional problems, that otherwise would be autonomous[3].

B. Welfare analysis

1) The non specified model: We want to characterize an optimal policy, i.e. a policy that maximizes:

$$W \equiv \int_0^{\infty} e^{-\rho t} \left\{ \sum_{i=1}^{N} \left[S_i P_i(A_i, S_i) + r_i\left(\bar{S}_i - S_i\right) - C(B_i) \right] - E(S) \right\} dt$$

s.t. (1), $S_i(t) \geq 0 \ \forall i \ \forall t$ and $S_i(0) = S_{i,0}$ given $\forall i$.

In the presence of an interior solution for the S_i's, the first order conditions are:

$$C'(B_i) = \lambda_i \ \forall i \in [1, N] \quad (2)$$

$$P_i(A_i, S_i) + S_i \frac{\partial P_i(A_i, S_i)}{\partial S_i} - r_i - E'(S) - \lambda\delta = \rho\lambda_i - \dot{\lambda}_i \quad (3)$$

$\forall i \in [1, N]$

$$\lim_{t \to \infty} e^{-\rho t} \lambda_i S_i = 0 \quad (4)$$

where λ_i is the co-state variable associated with the area of infrastructure in sub-region i.

2) The specified model: Consider the following specifications for P_i, C_i and E_i:

$$P_i = A_i S_i^{-\alpha}$$

$$C_i = \frac{\beta}{2} B_i^2$$

$$E = \frac{\gamma}{2} S^2$$

Where $(\alpha, \beta, \gamma) > 0$ are parameters. Notice that in these conditions, a corner solution is possible. However, it does not occur with the set of parameters that we use in our simulation. So, the following resolution focuses is only valid for interior solutions. With these specifications, (2) and (3) give:

$$\dot{B}_i = (\rho + \delta) B_i + \frac{1}{\beta} \left[(\alpha - 1) A_i S_i^{-\alpha} + r_i + \gamma S \right] \quad (5)$$

(1) and (5) constitute a system of 2N differential equations, and 2N variables (i.e. N B_i and N S_i).

N initial conditions are given for S, and the transversality conditions (4) give the missing border conditions to solve this model.

III. The Multiagent system

Simulation and economic concepts have to be merged in order to develop a common transdisciplinary framework for the modelling and simulation of land allocations. The simulation techniques have to make automatic the computations and the visualization of many data. Besides, regarding the system of differential equations obtained in the last section, initial building rates have to be determined according to the system parameters. An original method is designed to automatically determine it through an iterative convergence method, based on the initial parameters.

A. Background in simulation

In simulation, agent-based and cellular systems are two notions tangled up. A cellular system is a system composed of many interacting sub-systems called cells, regionally identical in behaviour. An agent-based system is composed of one ore many sub-systems (multiagent systems: MAS), situated in an environment, which are able to perform flexible and autonomous actions. Cellular systems can be agents themselves (the environment of an agent are other agents), or they can represent the agents' physical environment. Fig. 1 depicts the components of a generic land use model based on a discrete-time simulation. From the simulation point of view, each microregion is discretized through a cellular model and embedded into an agent. Hence, a MAS is constructed. Components and ports are used to achieve a full modular evolutionary simulation package. Nonetheless, modularity can be removed to enhance simulation performance (e.g., state access of neighbouring cells, see for more details). The Synchronizer component pilots the whole simulation and is in charge of the data exchanges (between cells and agents, and data initializations). The synchronizer has access to the dynamic (agents) and static data (cells) components. Inputs are received from the interface through the MAS input port. Agents embed the behaviour of microregions constituted as grid of cells. The Agents component updates a list of active (state changes) agents. This scanning algorithms allows to focus the simulation only on the active components (See [3], for more details), thus improving execution times.

B. Simulation of the land use model

Once defined the economic model, simulation becomes necessary for automatically storing, computing and visualising many data. Besides, when there are N>2 microregions, it is

[3]For example, a regional congestion effect could be introduced in each sub-regional inverse demand function.

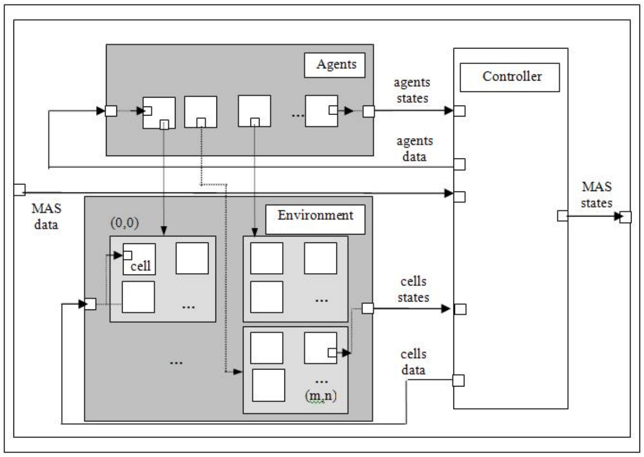

Fig. 1. MAS of the land use model

not possible to analytically solve the system so constituted of 2N coupled differential equations. Furthermore, the automatic allocation of new tourist parcels around remarkable sites can only be achieved through an original scanning algorithm. Finally, many digital data are needed to represent a region at field-scale. During the simulation, at each time step, in each microregion, starting from remarkable sites, scanning algorithms determine the agricultural parcels inclined to be converted to a tourist activity. At each time step, according to economic parameters modelled through differential equations, the tourist surface to be built is provided. Equations (1) and (5) are discretized through Euler's method. Fig. 2 depicts the implementation of agents' transition functions. Fig. 3 illustrates a snapshot of the interface developed to perform virtual experimentations. For each zone, local parameters (remarkable site, appealing value, number of agricultural parcels, number of tourist parcels, agricultural rent) are initialized through the interface. These parameters are stochastically determined and distributed in space according to range values. The distribution of tourist, agricultural and non constructible parcels can be visualised in space. The parameter of the building rate is considered to be given as a solution of the simulation model (cf. next sub-section). The interface allows too for the initialisation of the global parameters (for all zones): precision parameter (explained in the next section), discount rate, price elasticity, parameter of the external cost, depreciation rate as well as simulation parameters (time-step of the discretization and total simulation time).

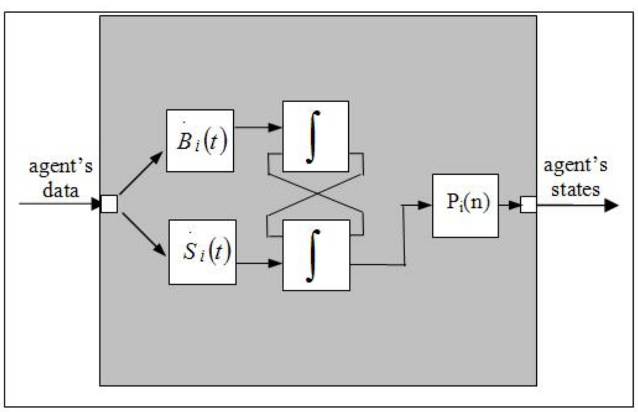

Fig. 2. Block diagram of the cells' functions

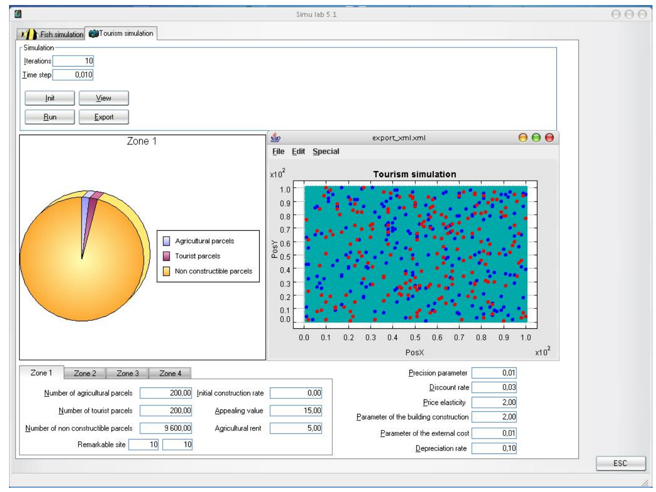

Fig. 3. Snapshot of 4 zones

C. *Implementation of the experimental conditions*

As depicted in Fig. 4, in simulation, at the conceptual level, there are the model and the experimental frame [7]. The model describes the structure and the behavior that are of interest for the study (as depicted in the two previous sub-sections). The experimental frame describes the circumstances under which the model is called up (i.e., an operational formulation of the objectives that motivate the study and the underlying assumptions and constraints). To be able to equally interpret the experimental frame concept as governing experimentation on a real system or on a model, two formulations have been proposed: a generation mode and an acceptance mode:

- In the generation mode, the set of admissible input segments for the model is realized by employing a generator, whose task is to generate inputs to the model
- In the acceptance mode, the real system is naturally fed by real data from which the experimental frame must select those of interest. This selection is realized by an acceptor, whose task is to accept or not data taken from its inputs (e.g., by generating as its output the value "yes" or "no").

In both cases, a transducer is used to convert the data for analysis and visualization. Also, an acceptor is used to check the values of the run control variables. Here the interest of this experimental frame is twofold. First, it allows to differentiate design purposes for external conditions of the model (initial input data, as maps of initial constructions) and purposes for the determination of initial conditions. If the former case has already be designed and experimented, the latter is defined here and constitutes an original contribution in

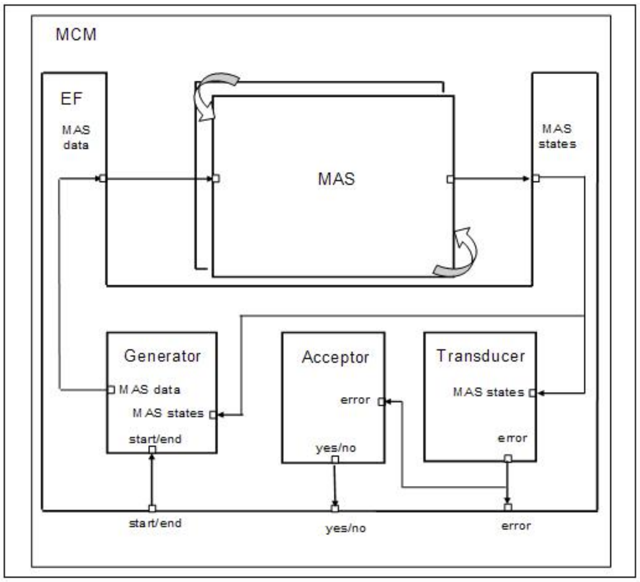

Fig. 4. Experimental frame of an economic MAS

economy. Indeed, experimental frames are used to implement the following algorithm of reverse shooting which determines the initial construction rate in an iterative loop:

Step 1: We compute the steady state value of the system described in the previous section. That is to say, we search a value for each B_i and each S_i such that $\dot{B}_i = 0$ and $\dot{S}_i = 0$ for all i.

Step 2: We linearize the system around the steady state computed at *step 1*. The variables of this model are S_i^l and B_i^l

Step 3: We compute a general non-diverging solution of the linearized system.

Step 4: We create a discrete dynamical system that is the opposite of the discretized version of the model described in the previous section. The variables of this model are S_i^d and B_i^d

Step 5: We choose an arbitrarily hight value of t, that we call t^{ini}, and then compute $B_i^l(t^{ini})$ and $S_i^l(t^{ini})$.

Step 6: We compute the system of *Step 4* for t^{ini} periods, with $B_i^d(0) = B_i^l(t^{ini})$ and $S_i^d(0) = S_i^l(t^{ini})$ as initial conditions.

Step 7: If there exist one i such that $\left(S_i^d(t^{ini}) - S_{i,0}\right)/S_{i,0} > \psi$ where ψ is a chosen precision coefficent, then we choose a higher value for t^{ini} and then go back to *Step 6*. Otherwize, we go to *Step 8*.

Step 8: we make the following approximation: $S_i(t) \approx S_i^d(t^{ini} - t)$. the algorithm is over.

IV. Conclusion

In this paper, we tried to explore the problem of the allocation of a scarce resource, land, between two sectors, namely tourism and agriculture. The original contribution has been to couple an economic model using the standard tool of optimal control with a MAS in order to simulate the long term evolution of the economy. A generic simulation method allows to automatically adjust the initial parameter of an optimal control system using the reverse shooting method. The simulation has been necessary to automatically deal with many data, as well as with many dynamic systems modelled by differential equations. Furthermore, we showed that this method could give interesting insight about the concentric conversion of land to tourist facilities. Nonetheless, this work in progress needs to be improved in several ways. We have to implement the model in the real world, it means in a case study. It will take us at estimating the parameters of our model using econometric regressions. But this case study will be the occasion to exploit the full possibilities of this theoretical framework by simulating tourism development using at time a MAS and a Geographic Information System (GIS).

Acknowledgment

The authors would like to thank Dominique Prunetti for his help and comments.

References

[1] Ioannou B.. *Tourist development impacts on the spatial transformation of the Greek islands*. Ersa working paper series n^o130, 2002.

[2] León C.J., Hernández J.M. & González M., "Endogenous lifecycle and optimal growth in tourism" in *CRENoS conference Tourism And Sustainable Economic Development: micro and macro issues*, Chia, Sardinia, 2003.

[3] Muzy A, Innocenti E., Barros F, Aïello A., Santucci J-F, "Efficient simulation of large-scale dynamic structure cell spaces" in *Summer Computer Simulation Conference*, Montréal, Canada. 378-83, 2003.

[4] Peña J., Bonet A., Bellot J. & Sánchez J.R., "Trends and driving factors in land use changes (1956-2000) in Marina Baixa, SE Spain" in *45th Congress of the European Regional Science Association*, Amsterdam 2005.

[5] Rey-Maquieira Palmer J., Lozano Ibáñez J. & Mario Gómez Gómez C., *Land, environmental externalities and tourism development*, in *Tourism Economics and Sustainable Development*, Lanza & al., Edward Elgar, 2005.

[6] Sahli M., Nowak J.-J., *Migration, Unemployment and Net Benefits of Inbound Tourism in a Developing Country*. FEEM Working papers series n^o148, 2005.

[7] Traoré M, Muzy A, *Capturing the dual relationship between simulation models and their context,Simulation Practice and Theory (SIMPRA)*, Accepted for publication, 2005.