# CURRENT RESEARCH RELATED TO AGENT-BASED MODELING AND LAND-USE / LAND COVER CHANGE

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My relation with agent-based modeling started with a spatial-dynamic model of structural change in agriculture that I have developed during my dissertation research in the early nineties at the Department of Agricultural Economics in Göttingen. In the meantime the modeling approach has been used in subsequent studies with respect to manifold research fields, such as policy analysis, structural change, and land use. In the remainder, I will illustrate the idea of the approach. I continue with present extensions as well as with related research.

### *Introduction: The Idea*

The original inspiration arose from the question whether and under which conditions structural change in agriculture may be path dependent (cf. Balmann 1995, 1999). The idea was to model and to simulate agricultural regions "from the bottom up" by considering a multitude of individually behaving farms that interact on certain product and factor markets. For instance, it is obvious that farms can increase their acreage only if there is land available in the farms' neighborhood - probably because neighboring farms reduce their acreage. Moreover, if a farm invests, this often has an impact on the farm's production capacities for the lifetime of the asset. The same holds for the capital stock that depends on previous investments as well as on previously gained profits. In such a model, the evolution of every farm depends on its own state and history as well as on the evolution of other farms, particularly the evolution of its neighbors. Once a simulation is started, the evolution of the region and thereby structural change would occur endogenously. Hence, such a model should allow the study of the impacts of sunk costs, factor mobility, and returns to scale on the direction and speed of structural adjustment.

To realize this idea, a spatial model was developed where farms are located at certain points on a chessboard-like spatial grid. The fields within the grid represent land plots that can be used for agricultural production. The farms compete for the land in repeated iterative auctions where every farm bids according to its marginal land productivity and its distance to the next available plot. Figure 1 gives a snapshot of a selected simulation run by showing how the land is distributed to different farms after a number of periods. Plots marked with an X represent locations of farms. Plots with the same color belong to the same farm.

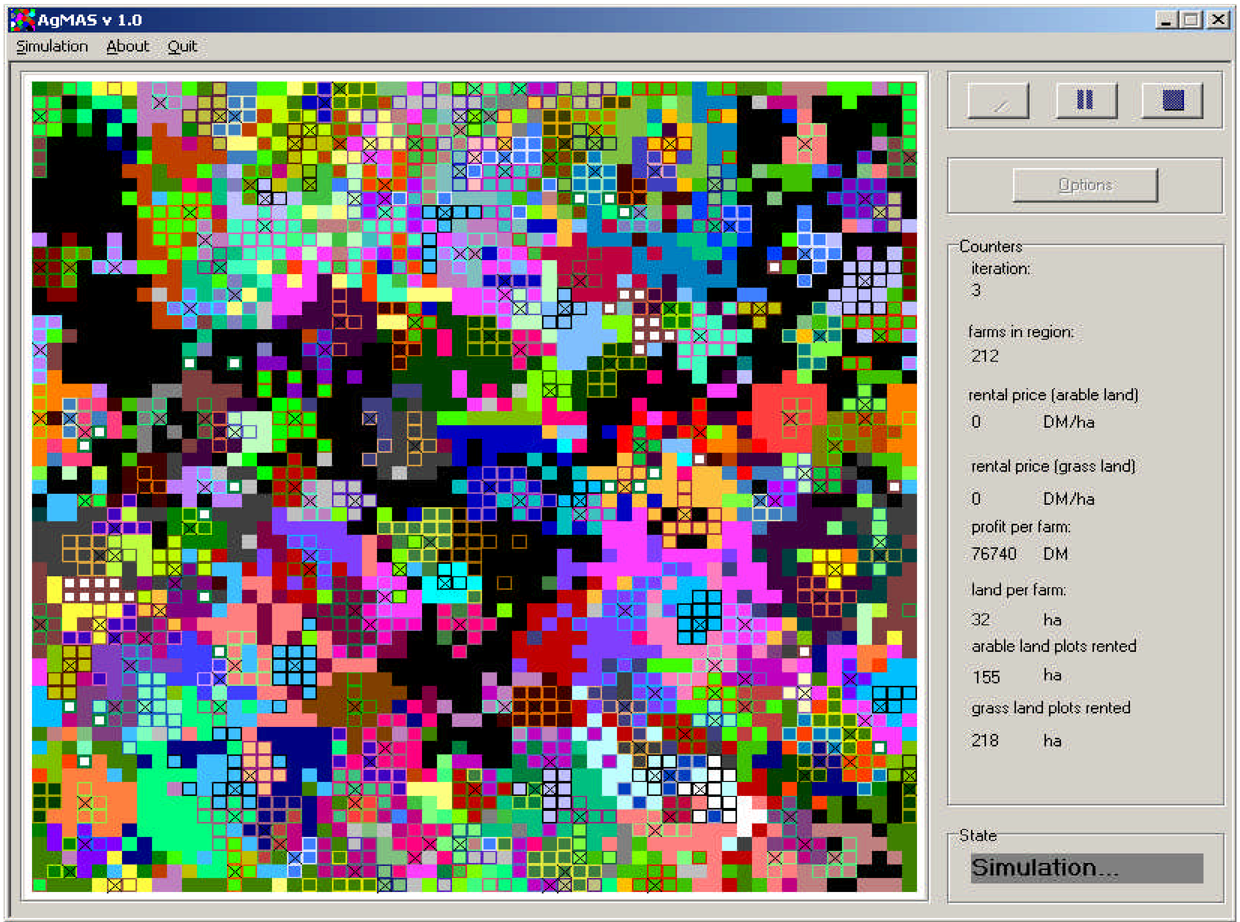


*Figure 1: Land distribution in a simulation with 1600 plots and 110 farms.*

Apart from renting and disposing land, the farms can engage in different agricultural production activities (e.g. dairy, cattle, hogs, sows, arable farming, pasture land) and they can invest in different assets (differently sized buildings for various activities, machinery of different sizes). In addition to the different production and investment activities, the farms can use their labor and capital for off-farm employment as well as to hire additional labor and to make debts. Moreover, farms can give up farming and new farms can be founded. Each of the farms can be understood as an agent that acts autonomously in trying to maximize the individual household income in response to expected market prices and the availability of land. All decision-making routines are based on adaptive expectations. Mixed Integer Linear Programming is used to optimize production activities and investment.

### *Extensions and Related Research*

The application of the model led to interesting results and insights regarding the question of path dependent structural change (Balmann 1995, 1999). This encouraged several subsequent studies:

a) Thomas Berger (1999, 2000) extended and refined the original modeling idea in several significant respects. Berger enabled the farms to follow heterogeneous decision rules, to communicate in information networks and to exchange land bilaterally. Further particular extensions were the introduction of heterogeneous land qualities and the integration of regional water resource systems that allow considering tradable water rights. Berger completely reprogrammed the model and applied it to a comparatively large agricultural region (with 5400 farms in a region of 667 $km^2$) in Chile to study the dynamic impacts of free trade-oriented policy options with regard to the diffusion of specific innovations and the resulting resource use change.

b) Balmann (2000) presents applications of the original model that focus on the dynamical impacts of selected agricultural policies on structural change, efficiency, land use, and farmers' incomes. The rather explorative simulations show the interrelation of these terms. Particularly, they show how subsidies like direct payments - which are often considered as non-distorting - may affect the speed and direction of structural change and thus they may also affect production and land use. In cooperation with Kathrin Happe (University of Hohenheim) these studies are enhanced and applied to selected regions in the German federal state of Baden-Württemberg. For instance, Balmann, Happe, Kellermann, Kleingarn (2001) analyze the adjustment costs of a policy switching that aims to reduce per farm animal density in the highly intensive agricultural area of Hohenlohe. The model considers explicitly some 2500 farms that are derived from a set of 12 real farms that are considered to be typical for the region.

c) A substantial part of the last mentioned project with Kathrin Happe is to develop the models to a well documented, basic model. This is done for two reasons. Firstly, a basic version shall allow third persons in a comparatively easy way to understand its structure and to adapt it for own projects as well as to extend it by additional features. Therefore, the actual programming exploits more consequently the object-orientation of C++ (cf. Happe 2000). The second reason for a basic, properly documented version may be paraphrased by the term "frankness". For instance, the model developed by Berger (1999) contains a source code of 17000 lines, corresponding to more than 300 pages of text (cf. Berger 1999, p. 5-39). Such a complexity means that the model is a black box for almost every addressee of the results and the mediation particularly of controversial simulation results is hardly possible. Standardization and frankness are seen as means to overcome such problems.

d) An obvious and straightforward extension is the integration of human decision making into such models. Real persons may replace the normative decision routines of individual farmers or of 'policy makers'. This idea is taken up in a joint project with Konrad Kellermann that develops the model's version discussed in c) towards an interactive computer game. The realization of this idea offers several perspectives for future use. The first is to use it for teaching. Students can apply textbook knowledge and can experience the often complex dynamic consequences of strategies. They may either take the role of a farmer who competes with other farms in the region or of a politician who tries to improve efficiency and/or the farmers' incomes. It will even be possible to link different 'regions' via a common market, so that 'politicians' of different regions can interact. A second perspective of the game is to study experimentally the behavior of players that take the role of farmers. It gives for instance a kind of benchmark to evaluate how 'smart' a particular computational decision making-routine is. Moreover, it is proposed to identify cognitive deficits of the present computational agents. A third, more visionary perspective is using the interactive model for planning purposes, like the analysis of local policies and dispute resolution, e.g., to manage conflicts between farmers and environmental interests. It is quite clear that this needs to adjust the model to the considered region.

e) Balmann (1998) and Balmann and Happe (2000) investigate whether economic models that are based on artificial adaptive learning may become a useful alternative to a normative behavioral foundation of the agents' behavior. The studies are based on a simplified comparative-static version of the model, presented above. Again, a number of agents (farms) that are spatially ordered on a grid compete for renting land. But in this model a genetic algorithm (GA) is applied to an agent specific population of genes representing particular bidding strategies in order to determine the agent's behavior. GA can be understood as a heuristic optimization technique that breeds solutions by applying operators known from natural evolution, such as selection, recombination (crossover) and mutation. Two principal market constellations are simulated for a variety of parameter constellations. First, a situation of limited market access is defined. A series of simulation experiments shows that for this scenario the model generates results that fit comparative static equilibrium conditions like allocative efficiency and zero-profits. Second, a limited market access scenario shows that only under very special conditions the distributed GA-model generates results that indicate oligopolistic behavior. Summarizing, nature related artificial intelligence methods like GA (and probably artificial neural networks too) seem to be promising alternatives for studying complex spatial processes. These positive experiences with using GA for analyzing complex microeconomic problems induced further work. In joint work with Oliver Mußhoff, GA are used to analyze real options problems of single firms as well as of competing firms.

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