Agent based modeling for agricultural policy evaluation: A review

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Abstract

In Agent-based computational economics economy is considered a complex system where the interactions between the economic agents are of ultimate importance. Simulating the economic system by modeling the behavior of the individual encompasses many advantages and certain epistemological issues are raised.

In the analysis of Agricultural Policy, the agent based modeling (ABM) approach has been employed for studying Land Use Changes (LUCC), the dynamics of structural changes, the transmission of innovations, the simulation of water use management and for environmental modeling. This approach can help overcoming various simplifying assumptions of the traditional models (like the "homogenous agent" assumption) or the difficulty in modeling interactions.

In this paper we initially do a short presentation of the principles of modeling economic systems with the ABM approach quoting its features, the advantages and disadvantages. Afterwards we make a discussion on the application of the ABM for modeling and evaluating agricultural policies and present four current application (Agripolis, Reg-MAS, MP-MAS, SWISSland). We finish this paper with some conclusions and suggestions.

Keywords: Agent based modeling, Agricultural policy evaluation, Agripolis, Reg-MAS, MP-MAS, SWISSland

Introduction

The terms “agent” and “multi-agent system” have been established on the scientific field of artificial intelligence as the abstract notion of autonomous units that react to environmental stimuli with the utter aim of fulfilling a certain goal. The use of ABM approach has originated from the computing science field to many others, like social, biological and environmental sciences. Niazi and Hussain (2011) have calculated an exponential increase to the number of publications from 1992 to 2008 . For that period the most popular fields on ABM were: Informatics, Ecology, Engineering, Social Sciences, Biology, Environmental Sciences, Mathematics, Operational Research.

Bandini and Manzoni et al. (2009) note that the common viewpoint on using ABM is that “the analytical unit is represented by an individual agent, acting and interacting with other entities in a shared environment and that the overall system dynamics is not defined in terms of a global function, but is rather the result of individuals' actions and interactions”. They also list the properties that an agent must possess: autonomy, social ability, reactivity, pro-activeness. In Gallegati and Riciardi (2009) ABM are defined as “models where (i) there is multitude of objects that interact with each other and with the environment; (ii) the objects are autonomous and (iii) the outcome of their interaction is numerically computed”. It is evident that the conceptual model of ABM fits very well to the social models. There is a wide range of terms related to ABM. Billari et al. (2006) list “social simulation”, “artificial societies”, “individual-based modeling”, “agent-based computational economics”. Ehrentreich (2008) refers to “agent based modeling”, “agent based simulation”, “microscopic simulation”. The former terminology reveals the close relation between ABM and simulation.

The implementation of most of the ABM is passing either through a programming language environment or through a framework that facilitates the agent-based simulation of the system in the space-time dimension. The use of OO programming language for the implementation phase is strongly recommended as the concept model of those languages fits perfectly well to the ABM one. In any case the modeler has to implement the theoretical behavior of the agents and their communication.

The classic book of Thomas Schelling “Micro motives and macro behavior” (1978) is considered the root of the ABM approach in the social sciences field. “ Santa Fe Institute

Artificial Stock Market" (1989) had also a prominent impact on the economics field. In Agricultural Economics, Screinemachers and Berger (2011) consider that ABM approach can be traced back to the Richard Day and Teodor Heihues (1960) recursive linear programming models for farm policy analysis. ABM reappears at the end of 1990 (Balmann 1997; Berger 2001; Parker, Manson et al. 2003) for modeling land use change using object oriented (OO) programming languages like C++. The ABM approach has the prime advantage of modeling the interactions of the individual farms and furthermore facilitates the incorporation of time and space dimension on the modeling process.

In the following chapters we will shortly refer to the general methodological framework of the ABM approach citing certain advantages and epistemological issues. Afterwards we attempt to connect ABM approach to agricultural policy evaluation giving certain examples. In the final chapter conclusions and suggestions are presented.

ABM Methodological framework: A short review

ABM is best suited for systems that have the two following properties (Axelrod and Tesfatsion 2012):

A) The system is composed of interacting agents. The interactions of the agents are forming the macroscopic equilibrium and so following a bottom-up approach, simulating the individuals' behavior can bring better results compared to a top-down modeling that is prone to failures.

B) The system displays "emergent properties". Bar Yam (1997) distincts two types of emergency, local and global. The first type is related to the definition of Gilbert et al. (2000): "A phenomenon is emergent if it requires new categories to describe it which are not required to describe the behavior of the underlying components". Local emergency is met in low complexity systems where the emergent properties are maintained to any part of the system. For example pressure and temperature of a gas, although properties of the system and not of its particles, are maintained even if we isolate a part it. On the other hand, global emergency is present only to the system as a whole. Bar Yam gives the example of a neural network, where memory is a property that is exhibited collectively by all neurons and by isolating a part of the "neural system" the property of memory is gone.

The above systems are defined as complex and the ABM approach adequately mimics their non-linear or even chaotic behavior. The classical algebraic or analytical methods cannot easily include the complexity of those systems and have difficulties computing their final state. As Bandini et al. (2009) writes, ABM should not be considered as merely a technique but also a unique approach for modeling complex systems. Axtell (2000) proposes the following modes of uses for ABM: (a). "Agent models as classical simulation", where ABM are used to replace the conventional modeling implementation without altering any modeling assumptions and (b) "Artificial agents as complementary to mathematical theorizing" where ABM is used as a modeling approach to tackle with complex systems.

Billari, Fent et al. (2006) mention a few advantages of using ABM: It is relatively easy to include feedback mechanisms; related to conventional mathematical modeling it is much easier to model heterogeneous and not fully rational agents; finally it is possible to construct and solve problems that are non-tractable by usual analytical models, i.e. Non linear systems or systems with a large number of interacting agents. Axtell (2000) also mentions: It is easy to limit agent rationality and model their heterogeneity; we can model systems that exist far from any type of equilibrium; time, space and social networks can be modeled.

Ehrentreich (2008) mentions as an epistemological issue the fact that ABM approach uses induction and not deduction. Axtell (2000) notes that compared to conventional mathematical methods, ABM fails in terms of robustness. Indeed the solutions are strongly dependant to the initial conditions of the simulation and a parametric exploration is usually necessary. Another issue is referred as the "black box" criticism: the difficulty to present the model insides, like the assumptions and the particular algorithms behind it, in a standardized and comprehensible manner since ABM are implemented in a programming language. The ODD protocol (Grimm, Berger et al. 2010) is a step towards overcoming the "black box" issue but compared to the conventional mathematical models a progress is still to be made.

Using ABM in modeling Agricultural Policy

We would suggest two different modes for using the ABM approach to model agricultural policy:

A) Firstly as a new technique for coping with issues that the conventional modeling approaches (mainly mathematical programming) cannot cope well, like the implementation of the interactions between the farms and the modeling of the farm's decision process with heuristics. Additionally the space-time dimension can be inherently implemented and managed. As it will later be presented, current efforts of using ABM modeling in agriculture are on this mode's trails.

B) The second mode is using ABM approach to model agricultural system as a complex adaptive system. Although in the economics field there have been quite a progress on this issue, agricultural economics seem to lack behind. So a theoretical breakthrough on this context is a prerequisite. We will try to present some pillars that this agricultural economics “breakthrough” could be based upon: the presence of auto-catalysis phenomena where certain rare events affects massively the final result. It is not safe to predict the outcome upon relying on the average (Gallegati and Richiardi 2009); focusing on the interactions between farmers or farms and focusing on how the social and economic networks affect the state of the system; the presence of path dependence on the agro-economic system; the system undergo major changes in phase transitions and not in a continuous way; analysis should focus on long-term results and social and other qualitative data should be taken under consideration. As Durlauf (1997) mentions this change of paradigm has important connotations for the agricultural policy-makers. The response of the system to the change of policy is not linear and continuous and alternative policies might not produce alternative results. A paper that is moving towards this paradigm is that of Weisbuch and Boudjema (2002) examining the agro-environmental policy.

The rest of this papers is focused on using ABM approach for evaluating agricultural policy on the first mode. ABM can be a worthy extension of the conventional mathematical programming modeling paradigm since the complexity of the agricultural system that stems from the multiplicity and variability of the interactions of agents is usually ignored in conventional models. In order to establish this argument, we will give a short description of the agricultural system from the scope of agricultural policy.

The producers of agricultural raw goods are the primal agents. They interact with other agents located in the supply chain, either in the input or output side. The decisions of the producers are utmost important to the policy makers as the production mix, the technology to use, capital investment and the withdrawal from agricultural activity. All of the above leads to the long term structural change of agricultural system (Balmann 1997). The decisions that the producers make are influenced by a multitude of factors: personal preferences (like the risk attitude) and the strategic (long term) aims that are very likely to differentiate from the conventional goal of maximizing profit or income; information availability and information processing capacity that are both affected by the social network of the farmer; cumulating experience and knowledge feedback mechanisms that lead to the evolution of the decision making process. It must also be considered that the distribution of the producers' decisions have a space and a time dimension which are usually ignored or downgraded in the conventional modeling approaches. Beside the production subsystem there also others of interest to agriculture policy makers. The environmental subsystem is a prominent example including parameters like biodiversity, the biophysical status, etc.

The above description reveals certain characteristics that according to Ehrentreich (2008) can justify the definition “complex system”: “Dispersed parallel interactions between many heterogeneous agents”, “Behaviors and strategies that are continuously adapted as agents learn and accumulate experience” and “Perpetual novelty that leads to new markets, new behaviors and technologies”.

As noted before, ABM approach can improve certain aspects of the conventional modeling methods. Berger (2001) states that the conventional models have two weaknesses: they ignore the interactions between actors and so ignore information and transaction costs (this is also noted on Balmann, 1997). Furthermore spatial dimension is not fully taken into account thus ignoring internal transport costs and land immobility. Kaye-Blake, Li et al. (2009) state that “ABM are most appropriate for systems characterized by a high degree of localization and dominated by discrete decision”. Millington, Romero-Calcerrada et al (2008) notes that an advantage of the ABM approach is the flexibility on modeling farmer's decision making process and the inclusion of non-economic factors which leads to a better representation of the regional - spatial variations in agriculture. Matthews, Gilbert et al. (2007), in an excellent review of agent based land-use models, locate the advantages of ABM approach to the incorporation of heterogeneity of the farms, especially in the cases where using average or typical representatives of the population can lead to faulty predictions. Another advantage they note is the ability of non-financial factors inclusion in the modeling of the decision making process and the potentiality of connecting the agent modeling process to environmental and social processes. Tzima, Athanasiadis et al. (2007) point out that the ABM approach is capable of facilitating the complexity of an irrigation management system: many stakeholders with different goals and the environmental dimension of the decision outcome. Weisbuch (2000) asserts that for environmental policy modeling a “bottom up” approach is more sensible than the “top-down” accounting counterpart. The latter misses to deal with uncertainties and in homogeneities in the appreciation of environmental values, distributive decision making and obedience of the constituents. Instead the ABM approach offers the possibility of modeling the long-term feedback interactions between the human agents and the environment.

Another potential use for ABM for agricultural policy modeling is its use as a virtual laboratory for experiments. The real-world data are not actually useful for medium or long term predictions and only by means of econometric or statistic methods can we deduce trends. Creating a virtual policy-oriented agricultural world where we can perform sensitivity analysis on all kind of sorts of parameters would be valuable. Finally, since the ABM is actually a distributed computing model there is the opportunity for parallel distributed solving of the models. In the context of agricultural policy modeling, especially in the case of country-wide modeling, we usually deal with many decision units and the solving times are long, ABM can offer significant speed up.

As a summary, we have pinpointed certain advantages of using ABM in agricultural policy modeling: the inherent encapsulation of time and space dimension; the potential for modeling interactions between the farmers, either directly or through simulating markets. In the following sections four current applications of ABM approach in agricultural policy are presented briefly. Table 1 compares and summarizes those applications.

Applications – Agripolis[1]

AgriPoliS (**Agri**culture **Pol**icy **S**imulator) is aiming at evaluating current or future policies for agriculture. Its root goes back to Balmann (1997) who programmed a simulation in order to explore the existence of “path dependency” in the process of structural change on the agricultural sector. It is programmed in C++ and neither the executable nor the source code is publicly available. Many assumptions that are closely related to the German agriculture are embedded on the simulator (Kellermann, Happe et al. 2008), but it has also been ported in many non-German cases. The conceptual framework of AgriPoliS is depicted on figure and the process overview on figure 2.

[1] http://www.iamo.de/agripolis/documentation/agripolis_v2-1.pdf

The main agent is the farm unit with a profit maximization goal. The decision process for the production is simulated as per farm mixed-integer linear programming problem. Production activities are distinguished into livestock production, plant production, short-term capital activities, short-term labor activities and “additional” activities (like manure disposal, machinery contracting, milk quota lease). The farms form short-term expectation on product prices concerning the next planning period. Also an exogenously long-term products’ price trend affects the model. Farm investment activity is typically concerned with the purchase of machinery, buildings, facilities and equipment. Production and investment are simultaneously considered in the mixed-integer planning problem.

Interaction between farms is taking place through markets for production factors and production outputs. There are various kind of markets (national and EU-wide, regional, regional and spatially organized), each with its specific organization described in the manual. In general, prices on the markets derive from a two element function; the first element is a general (exogenously) price trend and the second element is the price formation itself. Land market is considered a spatially organized market and exchanges occur exclusively via renting activities and an auction mechanism.

Space is modeled as an abstract landscape. FADN data and other regional statistics are used to calibrate this abstract landscape to statistical properties of the real landscape. A grid structure is used and each farm can own different and remote cells, with various soil properties. Each farm is located on a farmstead cell and owns plots and the transport costs are computed relative to each plot’s distance from the farmstead.

AgriPoliS has been used extensively to look into agricultural policies effects. For example, Happe and Balmann (2003) are simulating various alternatives of direct payments for an agricultural area of Germany and conclude that the EU Commision proposed changes (decoupled payments) will not significantly affect the agricultural structures. Happe, Balmann et al. (2008) are using AgriPoliS to investigate the effects of decoupling to the production mix and the land use changes for two heterogeneous areas of Germany. They remark that the econometric approach is less reliable to assess the effects of decoupling since the latter is a major shift to the state of the agricultural system. Happe, Hutchings et al. (2011) are using AgriPolis to examine the relation of the regional farming structure and the regional nitrogen loss. They link the simulation of the farm structure evolution for two agricultural policy scenarios with a Farm Nitrogen model.

Applications – RegMAS[2]

RegMAS (**Reg**ional **M**ulti **A**gent **S**imulator) (Lobianco 2008) is an open source multi-agent framework developed in C++ and based on AgriPoliS, although the code is written from scratch. It is designed for long-term simulations of effects of government policies over agricultural systems. FADN statistics and GIS data (corine land cover data) are required for applying RegMAS to another region. The available GUI and the default region that is included is very helpful and the model input is given through OpenDocument Spreadsheet files. In order for someone to modify the agents' behavior, one has to modify the appropriate classes on the available source code. In figure 4 the applications flowchart is presented.

The central agent is the farm agent. Each farm agent has a farmstead located in a specific site. The farm's objective is the maximization of household income. This is done through solving a farm-specific typical mixed integer mathematical programming (activities, resources, etc.). Investments are included in the maximization problem as activities that generate results over multiple years. Plots are considered as individual resources and each spatial activity is considered for each plot. Product prices are defined exogenously.

The agents' interaction is modeled through a land exchange mechanism where farmers can rent available land for a random fixed period. This mechanism works as follows: "Farmers can only rent land owned by an anonymous agent that collect the land arising from farms leaving the model and from the initial pool of rented plots to make it available in a bid to the farmer offering the highest price. Farmers asked to bid offer a share of their shadow price for such plot, to take into account of fixed and variable negotiation costs and overheads. The shadow price for the new plot is calculated simply performing two MIP problem optimization, with and without the plot, and calculating the difference.". For computational efficiency purposes, the bid offer is limited to a certain radius from each farm,

Lobianco (2010) is using RegMAS to investigate the effects of decoupling in an area of central Italy for the period 2008 – 2015.

[2] http://Time stepwww.regmas.org/

Applications - MP-MAS[3]

MP-MAS (**M**athematical **P**rogramming-based **M**ulti-**A**gent **S**ystems) is a multi agent application with "the purpose of understanding how agricultural technology, market dynamics, environmental change and policy intervention affects a heterogeneous population of farm households and the related agro-ecological resources". It combines constrained optimization models with biophysical production functions for irrigation and fertilization (Schreinemachers and Berger 2011). It is programmed in C++ and the binary is freely downloadable (maximum number of agents is 50). The source code is available after contacting the authors. The input files are given to the program as a set of 14 excel spreadsheets. Figure 5 and 6 depict the applications data layers and process overview respectively.

The agents represent farm households and each of them have attributes like the location of the farmstead, the locations of their fields, the individual household composition (age, sex, labor supply), available resources, membership in a population cluster and in an innovation segment. The decision making process is modeled as an individual mixed integer mathematical programming problem. The objective function can be defined either as expected net farm income, net household income or a multi-dimensional utility function that includes income and consumption. In figure 5 the sequence of the simulation steps is depicted. The agent population is initialized with a monte carlo technique from the a sample of real farms deriving from surveys.

Interactions between agents is taking place through the land and water local market and technology diffusion. Agents rent out and acquire units of land or water if the shadow price for a resource is below the average price. Resources are temporarily exchanged with highest bidding agents and an internal transport cost favors market transactions between neighboring agents. Agent interactions in technology diffusion are implemented as frequency-dependent contagion effect.

Space is modeled as a grid and the simulation runs on annual steps, although seasonal or monthly constraints can be introduced in the mathematical programming matrix for labor supply or water availability.

MP-MAS is appropriate (Berger, Schreinemachers et al. 2009) for exploring systems where there are irrigation issues, soil degradation and technology diffusion, especially for

[3] https://mp-mas.uni-hohenheim.de/

developing countries. On the application's homepage, there are several papers that use MP-MAS mainly on developing countries agricultural sector.

Applications - SWISSLAND[4]

SWISSland (StrukturWandel InformationsSystem Schweiz) aims to depict as realistically as possible the whole of Swiss agriculture in order to improve the forecasting accuracy of any policy change modeling. It is programmed in Repast-J, an ABM java framework, and linked to a MySQL database and to GAMS optimization routines. FADN farms are distributed representatively to space. Neither binaries or source code are available to public.

Agents are farms and belong to various Swiss agriculture specific categories (private summer farms, summer farms with public/private right systems, home-farms). The production activities are mainly animal sector activities. Decision process about production is represented by an mathematical mixed integer linear programming problem which maximizes the total agricultural household income and which is limited by farm factor endowments.

Although SWISSland is not spatially explicit and no land market is implemented, transportation costs for cattle, product and labor are included in calculations.

Like in previous applications the agents' decision process is modeled as a farm optimization problem and the interaction takes place in the land market (Mann, Möhring et al. 2010). In figure 3 the technical design and data-flow is depicted.

[4] The ODD protocol can be found at http://www.agroscope.admin.ch/soziooekonomie/04748/04749/index.html?lang=de&download=NHzLpZeg7t,lnp6I0NTU042l2Z6ln1acy4Zn4Z2qZpnO2Yuq2Z6gpJCFdIB_fGym162epYbg2c_JjKbNoKSn6A--

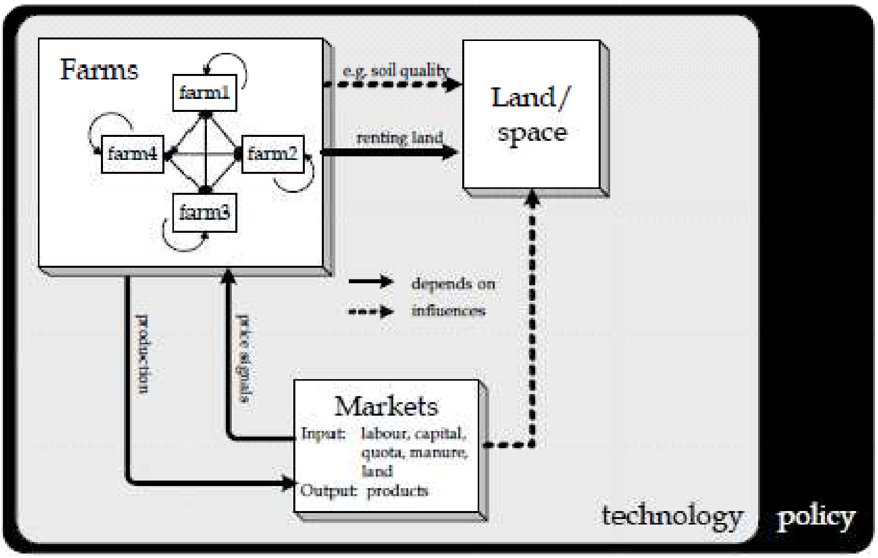

Figure 1, Agripolis conceptual framework (Source:Happe, Kellermann et al. 2006)

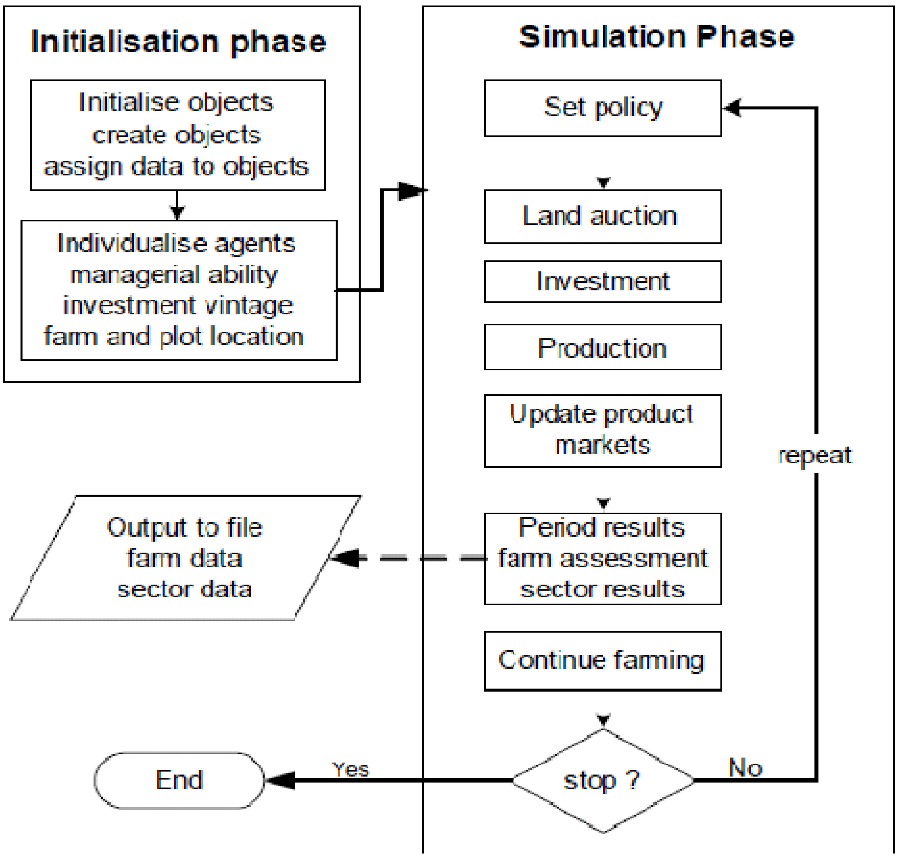

Figure 2, Agripolis process overview (source: Agripolis manual, version 2.1)

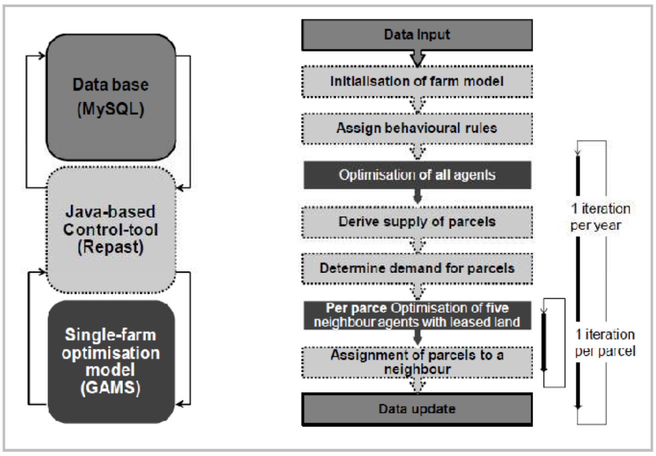

Figure 3, Techical design and data flow of SWISSland (Source:Mack, Mohring et al. 2011)

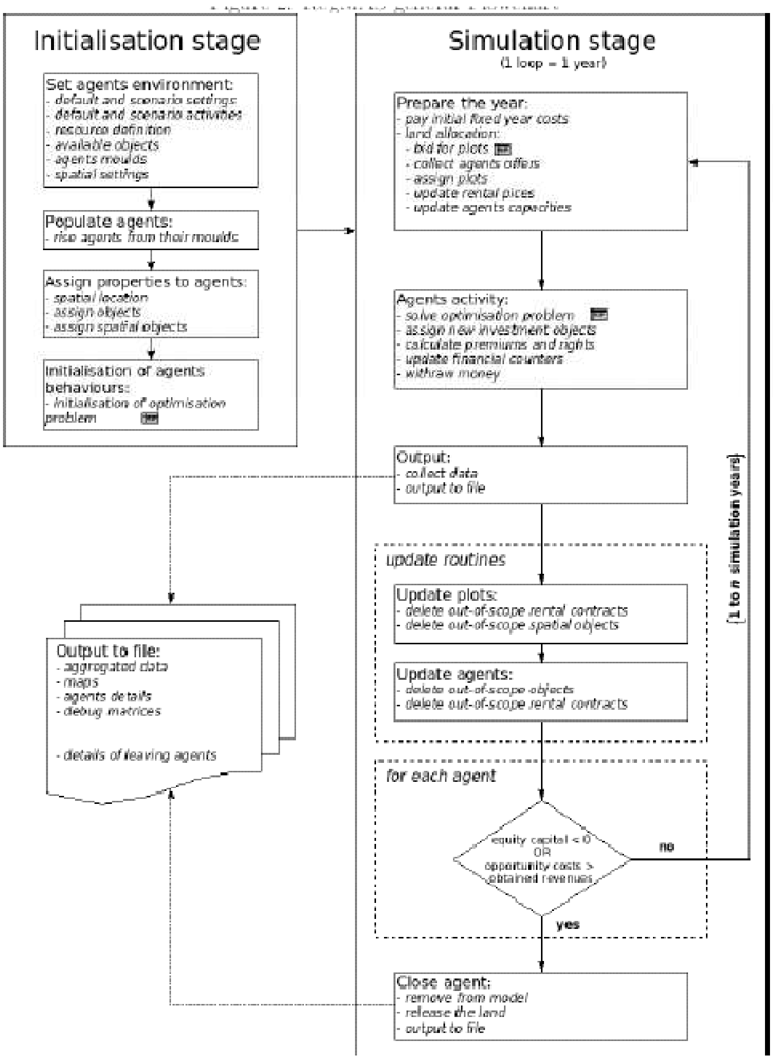

Figure 4, RegMAS model flowchart (Source:RegMAS user manual, v1.3)

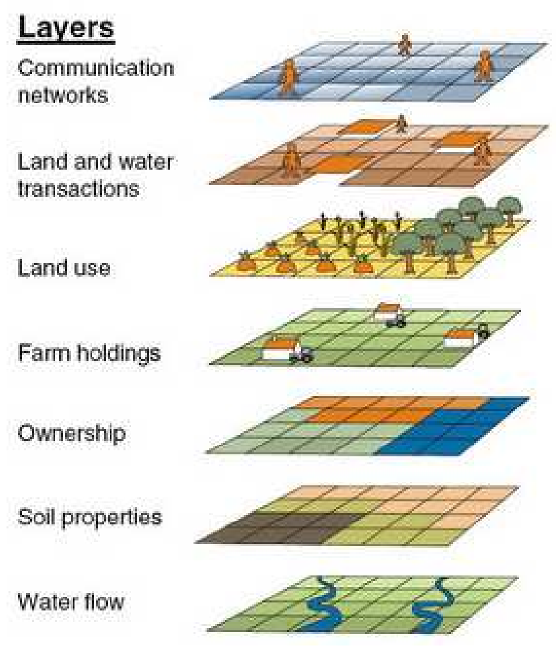

Figure 5, Data layers of MP-MAS application (Source:https://mp-mas.uni-hohenheim.de/)

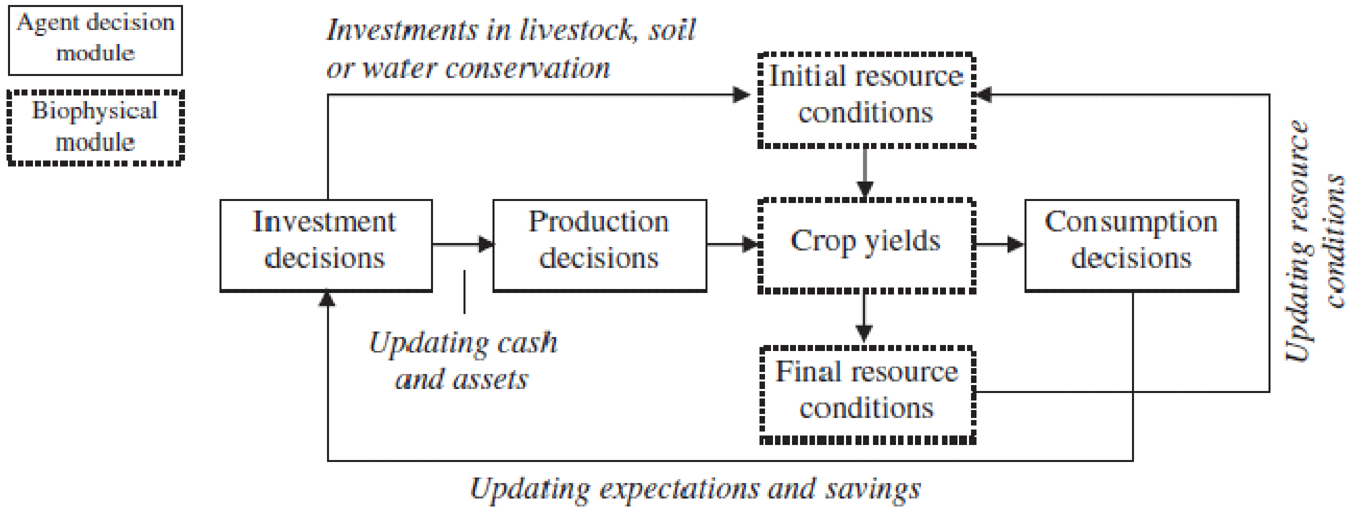

Figure 6, Process overview of MP-MAS (Source: Schreinemachers 2011)

	Agripolis	RegMAS	MP-MAS	SWISS-Land
Purpose				
	"A spatial and dynamic agent based model that simulates regional structural change in agriculture based on economic consideration" (Happe 2011)	"A spatially explicit multi-agent model framework, designed for long-term simulations of effects of goverment policies on agricultural systems" (Lobianco 2010)	"To understand how agricultural technology, market dynamics, environmental change and policy intervention affect heterogeneous population of farm households and the agro-ecological resources these households command" (Schreinemachers 2011)	"An ex-ante analysis and forecast of the impact of political changes in Swiss agriculture until 2020" (SwissLand ODD protocol)
Implementation Details				
Programming language	C++	C++ with GUI	C++, OSL	Repast J, GAMS
Input Data	FADN, Other regional surveys	FADN, Corine Land cover	Excel workbooks	MySQL database
Development model	Closed	Open Source	Binary available (limited to 50 agents)	Closed
Agents				
Main Entities	Farm unit	Farm household	Farm household	Farms
Decision making	Mixed integer mathematical programming	Mixed integer mathematical programming	Mixed integer mathematical programming	Mixed integer mathematical programming (PMP)
Interactions				
	Land market, implementation of product markets, labor, capital markets	Land exchange mechanism	Land and water local market, Innovation diffusion	No market implemented
Spatial dimension				
	Grid, abstract landscape	Grid, Spatially explicit from FADN and Corine databases	Grid	No spatial dimension
Temporal dimension				
	Annual time step	Annual time step	Annual time step	Annual time step

Table 1, Ssummary of four ABM applications for evaluating agricultural policy

Conclusions-Proposals

ABM approach for evaluating current or future agricultural policy alternatives is ripe. Apart from the applications that has been presented in this paper, there are many significant reviews on the subject of understanding land use change in agricultural landscape: Matthews, Gilbert et al. (2007); Kaye-Blake, Li et al. (2009); Parker, Manson et al. (2003). There are also other significant but more focused papers: Millington, Romero-Calcerrada et al. (2008); Kaufmann, Stagl et al. (2009); Freeman, Nolan et al. (2009); Le Bars, Attonaty et al. (2005).

The current ABM applications are aiming, one way or another, to simulate reality as accurately as possible. This results in over-specialization and incorporation of assumptions that makes it difficult to port to other cases. The majority of them are spatial-temporal models that resort to mathematical programming for modeling farmers decision making process and to market mechanisms for interactions.

There are issues that would be of great research interest for the agricultural policy evaluation, like studying the role of supply chain, using alternative paradigms for modeling farmers' decision making process and investigating how the function of the factor markets affect producers' decisions. Creating a domain specific language for ABM in agricultural policy is another, non-trivial, proposal. This would give the chance to researches with not special skills in a programming language to create and explore their own models on agricultural policy.

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