DISCUSSION PAPER

Institute of Agricultural Development in Central and Eastern Europe

THE AGRICULTURAL POLICY SIMULATOR (AGRIPOLIS) – AN AGENT-BASED MODEL TO STUDY STRUCTURAL CHANGE IN AGRICULTURE (VERSION 1.0)

KATHRIN HAPPE, ALFONS BALMANN, KONRAD KELLERMANN

DISCUSSION PAPER NO. 71
2004

Theodor-Lieser-Straße 2, 06120 Halle (Saale), Germany
Phone: +49-345-2928 110
Fax: +49-345-2928 199
E-mail: iamo@iamo.uni-halle.de
Internet: http://www.iamo.de

Kathrin Happe MA(Econ) is a research scholar at the Institute of Agricultural Development in Central and Eastern Europe (IAMO), Division: Structural Development of Farms and Rural Areas, in Halle (Saale), Germany. Her research mainly focuses on agent-based modelling, structural change in agriculture, agricultural policy analysis, efficiency analysis, and multifunctional agriculture.

Prof. Dr. Alfons Balmann is managing director of IAMO and head of the division Structural Development of Farms and Rural Areas. His research interests are in agent-based modelling in the field of structural change and real options analysis.

Dipl.-Ing. agr. Konrad Kellermann is research assistant at IAMO, Division: Structural Development of Farms and Rural Areas. His research focuses on agent-based modelling with a special interest on modelling learning on agricultural land markets.

Mailing address:	Institute of Agricultural Development in Central and Eastern Europe (IAMO) Theodor-Lieser-Straße 2 06120 Halle/Saale Germany
Phone:	+49-345-2928 322
Fax:	+49-345-2928 399
E-mail:	happe@iamo.de
Internet:	http://www.iamo.de

ISSN 1438-2172

ABSTRACT

A central criticism common to agricultural economic modelling approaches for policy analysis is that they do not adequately take account of a number of characteristic factors of the agricultural sector. This concerns aspects like the immobility of land, heterogeneity of farms, interactions between farms, space, dynamic adjustment processes as well as dynamics of structural change. In brief, modelling the complexity of the system has not been at the centre of interest. In terms of modelling complex economic systems, an agent-based modelling approach is a suitable approach to quantitatively model and understand such systems in a more natural way. In the same way, this applies to the modelling of agricultural structures. In particular, agent-based models of agricultural structures allow for carrying out computer experiments to support a better understanding of the complexity of agricultural systems, structural change, and endogenous adjustment reactions in response to a policy change. This paper presents the agent-based model AgriPoliS (Agricultural Policy Simulator) which simultaneously considers a large number of individually acting farms, product markets, investment activity, as well as the land market, and a simple spatial representation. The ultimate objective of AgriPoliS is to study the interrelationship of rents, technical change, product prices, investments, production and policies, structural effects resulting from these, the analysis of the winners and losers of agricultural policy as well as the costs and efficiency of various policy measures.

JEL: Q12, Q15, Q18

Keywords: Agent-based systems, Multi-agent systems, Policy analysis, Structural change, Simulation.

ZUSAMMENFASSUNG

Ein oft genannter Kritikpunkt an vielen agrarökonomischen Politikanalysemodellen ist, dass diese nur ungenügend Bezug nehmen auf Aspekte wie die Immobilität von Boden, Heterogenität der Akteure, Interaktionen zwischen Betrieben, räumliche Bezüge, dynamische Anpassungsprozesse und Strukturwandel. Kurz, die Modellierung komplexer Wirkungszusammenhänge steht weniger oder nicht im Zentrum des Interesses. Agentenbasierte Modelle stellen einen Weg dar, das Verständnis komplexer ökonomischer Zusammenhänge zu verbessern bzw. zu quantifizieren. Insbesondere erlauben sie die Durchführung von einer Vielzahl von Computerexperimenten, mit denen Fragestellungen wie der Zusammenhang zwischen Politikmaßnahmen und Strukturwandel untersucht werden können. Basierend darauf, stellt dieser Beitrag das agentenbasierte Modell AgriPoliS (Agricultural Policy Simulator) vor. AgriPoliS ist ein räumlich-dynamisches Modell einer Agrarstruktur, in dem eine Vielzahl individuell abgebildeter landwirtschaftlicher Unternehmen in einer vereinfacht dargestellten Agrarregion agiert und beispielsweise um begrenzt verfügbare landwirtschaftliche Flächen konkurriert.

JEL: Q12, Q15, Q18

Schlüsselwörter: Agentenbasierte Systeme, Politikanalyse, Multi-Agentensysteme, Strukturwandel, Simulation.

CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

Farm agent (k=1,…,K)

Z	Utilised agricultural area of farm
LU[1)]	Stocking density per farm
MP	Manpower hours
m	Managerial ability factor
A (c=1,...,S)[2)]	Fixed assets
$\mathbf{A}_{ec}$(c=1,...,S)	Equity financed share of assets
n_c	Vintage of asset
LA	Land assets
L	Liquidity
EC	Equity capital
BC	Borrowed capital
MR	Minimum equity capital reserve
Y	Farm household income
Y^e	Expected farm household income
GMA	Gross margin agriculture
IR	Interest on working capital
$BID_{y,z}$	Bid for wanted plot $P_{y,z}$
RE	Rent paid
S	Support payments
MC	Current upkeep (maintenance)
D	Depreciation
OV	Farming overheads
TC	Transport costs
IC	Interest paid
HW	Wages paid
W	Off-farm income
WD	Withdrawal for consumption
WD_{min}	Minimum withdrawal
ε	Additional consumption

Capital

CRF	Capital return factor
i_{ec}	Interest on equity capital
i_{bc}	Interest on borrowed capital
i_{bcs}	Interest on short-term borrowed capital

Investment

I (h=1,…,H)	Investment to produce i
d (d=1,…,D)	Investment type
v	Equity-finance share
A	Investment costs
AC	Average annual costs
N	Useful life
MC	Maintenance costs p.a.
l	Technical change factor machinery
f	Technical change factor buildings and equipment
LS	Labour substitution

Plot

$P_{y,z}$	Plot at grid position y,z
β	Bid adjustment
$R_{y,z}$	Rent paid for plot $P_{y,z}$
AP	Average number of adjacent plots per farm
$TC_{y,z}$	Transport costs between farmstead and plot
T	Number of adjacent plots
$DI_{y,z}$	Distance between plots
R	Average rent in region

Production activities

x (i=1,...,I)	Production activity
c (i=1,...,I)	Variable prod. cost
$\mathbf{c}^e$ (i=1,...,I)	Expected variable costs
$\mathbf{p}^e$ (i=1,...,I)	Expected product price
γ	Price trend
b (j=1,...,J)	Factor capacities
q (j=1,…,J)	Shadow price of **b**
r (j=1,...,J)	Factor demands

---

1 One livestock unit corresponds to approximately 500 kg alive weight.

2 Bold letters denote vectors.

1 INTRODUCTION

Quantitative modelling has traditionally played an important role in agricultural economics, with a focus on agricultural policy impact analysis. The goal of agricultural policy analysis is to study the effect of agricultural policies at different levels of scale, i.e., at the global, national, sector, regional or farm scale, along indicators such as efficiency or income. Quantitative models typically used are partial or general equilibrium models, econometric models, and mathematical programming models.

The type of modelling approach chosen depends on the type of policy to be analysed and the question of interest. Partial and general equilibrium models, for example, are primarily aimed at the evaluation of trade policies or the market impact of coupled domestic price support policies.[3] In particular, trade models take an aggregate look at agricultural production. With regard to individual types of farms, these models resort to the definition of 'representative farms' to represent the behaviour and characteristics of a group of farms. However, if the goal is to analyse process-oriented policies, such as direct payments as implemented by the Common Agricultural Policy reform in 1992, partial or general equilibrium models easily run into difficulties because the level of aggregation in many models does not allow to model land allocation distortions, to give and example.

Process-oriented policies can more easily be analysed with econometric models (e.g. OUDE LANSINK and PEERLINGS, 1996; OUDE LANSINK and PEERLINGS, 2001, GUYOMARD et al., 1996) or normative mathematical programming models (e.g. KAZENWADEL, 1999; HANF, 1989; JACOBS, 1998; SCHLEEF, 1999; BALMANN et al., 1998a, b). However, econometric models face the problem that parameters are estimated for pre-reform data (SALVATICI et al., 2001). Many mathematical programming models are, in fact, farm-based models. Farm-based models such as individual farm models, representative farm models, group farm models, and farm sample models, explicitly view the problem from a micro-perspective, that is, the perspective of the individual farm or a group of farms. However, often there is an inconsistency between individual farm behaviour and resulting market effects at higher levels of scale. This aggregation problem can be eased by weighting individual farms to represent, for example, regional capacities (e.g. BALMANN et al., 1998a, b; KAZENWADEL, 1999). Moreover, normative models are 'closed' models in that farms are allowed to adjust within a given possibility range; many times, these models also disregard changes in farming structure and changes in farming technology (BERGER and BRANDES, 1998).

A criticism common to all modelling approaches discussed thus far is that they neglect a number of characteristic factors of the agricultural sector. In particular, aspects like the immobility of land, heterogeneity of farms, interactions between farms, space, dynamic adjustment processes as well as dynamics of structural change have not – or in a limited way – been taken into account. In brief, modelling the complexity of the system has not been at the centre of interest.

In spite of this, agricultural economists have viewed (regional) agricultural structures as complex dynamic systems already since the early 1960s (e.g. HEIDHUES, 1966; DE HAEN, 1971; BERG, 1980; DAY, 1963; BRANDES, 1978 and 1985; LENTZ, 1993; BALMANN, 1995;

[3] A comprehensive list to references and applications for these types of models is given in HECKELEI, WITZKE, and HENRICHSMEYER (2001) as well as SALVATICI et al. (2001). Examples are ESIM (MÜNCH, 2002), GTAP (HERTEL, 1997), SWOPSIM (e.g. RONINGEN et al., 1991), WATSIM-AMPS (KUHN, 2003), and FAPRI (e.g. FAPRI, 2003).

FINKENSTÄDT, 1995). With respect to agricultural structures, complexity mainly arises due to the following characteristics of an agricultural structure:

- *Heterogeneity of farms:* An agricultural structure can be understood as a decentralised system with heterogeneous, individual farms. Among others, farms differ with respect to their size, type, factor endowment, organisational form, managerial ability, and the age of the farmer.
- *Interdependencies*: Farms within an agricultural structure are not independent from each other. Rather, there are interdependencies between farms via institutions such as markets for land and quota, or by way of shared resource use. For example, farms usually can only increase their acreage if other farms reduce acreage or close down.
- *Dynamic adjustment processes:* Farms within an agricultural structure constantly adjust to changing framework conditions given by markets, production location, policies, or external shocks. Farm factor endowments, the financial and personal situation determine the degree and pace of adjustment. Because of individual actions of farms, regional agricultural structures are subject to constant change. Furthermore, macro results such as market prices or structural change are the combined effect of individual farm activities. They feed back into determining the behaviour of individual farms.
- *Path dependencies:* A system is path-dependent if its development is determined by its history; the system may be locked-in to a particular state or development path (cf. ARTHUR et al., 1997, ARTHUR, 1989; BRANDES, 1995; BRANDES, 1978; DAVID, 1985). A path once taken can only be left at high costs. Path dependencies are often associated with technological change, and in particular with respect to technologies with positive returns to scale (ARTHUR, 1989; DOSI, 1997). BALMANN (1995) and BALMANN et al. (1996) have shown agricultural structures to be path dependent without strong positive returns to scale. Regarding agricultural structures, path dependencies can be found both at the individual farm level as well as in agricultural policy making. At the farm level, path dependencies are caused, e.g. by quasi-fixed production factors which may hold up adjustment processes. At higher levels of scale, institutional arrangements as well as certain agricultural policies may cause path dependencies (cf. BALMANN et al., 1996).

In terms of modelling complex economic systems, an agent-based modelling approach is a suitable approach to quantitatively model and understand such systems in a more natural way. In the same way, this applies to the modelling of agricultural structures. In particular, agent-based models of agricultural structures allow for carrying out computer experiments to support a better understanding of the complexity of agricultural systems, structural change, and endogenous adjustment reactions in response to a policy change. In this sense, an agent-based model of agriculture would provide one answer to STOKER'S (1993) request "... to build empirical models that are applicable to the applied question of aggregate data, but retain the feature of modeling behavior at the individual level."[4]

This contribution presents the agent-based model AgriPoliS (Agricultural Policy Simulator) which is an agent-based model of agricultural regional structures. Central elements of AgriPoliS such as the conceptual framework, data structure, and variables take on previous work by BALMANN (1995, 1997). The model name, AgriPoliS, refers to the main application of the

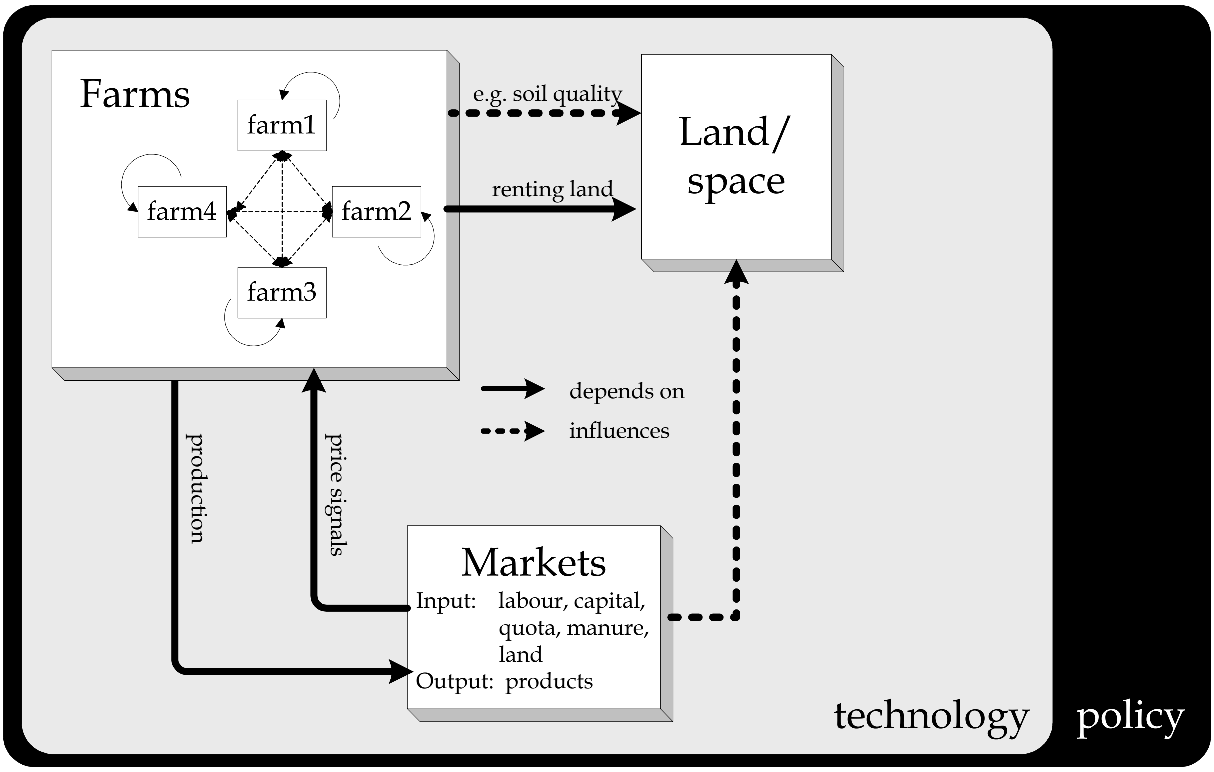
[4] It is interesting to note that Stoker at no place in his survey article mentions agent-based methodologies. However, at the same time, with his line of argumentation and conclusions, he sets the ground for agent-based models.

model, which is the impact analysis of agricultural policies on structural change.[5] The model maps the number of farms, selected farm characteristics as, the production structure and land use of the region in a certain base period. The structure of the paper is as follows: Section 2 sets out the conceptual framework of AgriPoliS. Section 3 presents the implementation of the conceptual framework as an object-oriented computer programme. Based on this object-oriented representation, in sections 4 through 7 define key objects and agents. Section 8 discusses the model and concludes.

2 CONCEPTUAL FRAMEWORK

The core of AgriPoliS is the understanding of a regional agricultural structure as a complex evolving system. This regional agricultural system is shown schematically in Figure 1. The figure shows the interactions between the three central components of agricultural structures: Farms, markets, and land.

Figure 1: Static conceptual model of a regional agricultural system



Source: Own figure.

This representation can be considered typical for family-farm dominated regions in Germany where production cannot take place entirely independent of land. A number of individual farms evolve subject to their actual state and to changes in their environment. This environment consists of other farms, factor and product markets, and space, which are again all embedded within the technological and political environment. Farms, land, and markets either directly depend on each other or they exert influence on each other. A direct dependence implies that one component cannot exist without another. The mutual dependence between

[5] Based on AgriPoliS, KELLERMANN (2002) has developed the interactive policy simulation game 'PlayAgriPoliS', which can be used, for example, for instructive use in the classroom. PlayAgriPoliS allows the player to take the position of an agricultural minister and to set a variety of policies and policy combinations.

farms, land, and markets results from the fact that farms require land to produce on the on hand. Farm management practices in return influence the state of the land the quality of which is characterised, for example, by soil fertility. On the other hand, the mutual interdependence between farms and markets takes place because farms can purchase production inputs on factor markets and sell products to product markets.

Representing this system using the abstraction of an agent-based system is appealing, not only because the description in Figure 1 suggests interpreting farms as individual agents. Also markets – be it product or factor markets, and in particular the land market – can be interpreted as agents that bring together and co-ordinate market activity. Before translating the conceptual model into a computer simulation programme in the following, the core contents will be sketched in more detail along the following questions:

- What are the agents involved and what makes them heterogeneous?
- How do agents behave and what actions are driving the system?
- What makes up the individual agent's spatial, technical, and political environment?
- How do interactions between agents, and agents and the environment take place in the model?

2.1 Agents involved

For the purpose of AgriPoliS an agent is defined as an entity that acts individually, senses parts of its environment and acts upon it (FERBER, 1999; FRANKLIN and GRAESSER, 1997; GILBERT and TROITZSCH, 1999; RUSSEL and NORVIG, 1995; LUCK et al., 2003; JENNINGS et al., 1998). In the context of regional agricultural structures, it is useful to differentiate between two kinds of agents: The farm agent and the market agent.[6] The agents in AgriPoliS are acting entities that actively carry out defined actions.

There are two types of agents in AgriPoliS, farm agents, and market agents. Of the two kinds of agents considered, the farm agent is the most important one. In the context of AgriPoliS, one farm agent corresponds to one farm or agricultural holding. In accordance with the above agent definition, a farm agent is an independently acting entity that decides autonomously on its organisation and production to pursue a defined goal (e.g. farm household income maximisation). Furthermore, a farm agent reacts to changes in its environment and its own state by adjusting its organisation in response to available factors endowments and observable actions of other farm agents.

The second kind of agent, the market agent, coordinates the working of markets. It is the responsibility of the market agent to bring together supply and demand of goods (products, production factors) and to determine a price of the good. More specifically, in AgriPoliS, there is a land market agent, the auctioneer, and a product market agent. Unlike the farm agent that meets all the criteria mentioned in the agent definition mentioned in the agent definition above, the market agents can only be considered as very basic agents, whose sole objective is to co-ordinate the actions of farm agents on the markets for products, land, capital and labour.

[6] In fact, there is also a third kind of agent that manages the course of actions of the other agents. The management agent coordinates the activity of farm agents and market agents in the simulation programme. It is responsible for initiating the actions carried out be the other two agents.

2.2 Farm agent actions and behaviour

Farm agents can produce a selection of goods. In order to produce, farm agents utilise buildings, machinery, and facilities of different types and capacities. With respect to this, AgriPoliS implements economies of size as with increasing size of production, unit investments costs decrease. Moreover, labour is assumed to be used more effectively with increasing size. AgriPoliS also aims to mimic the effect of technological progress. More specifically, it is assumed that with every new investment, unit costs of the product produced with this investment decrease by a certain percentage.

Farms can engage in rental activities for land, production quotas, and manure disposal rights. Labour can be hired on a fixed or on a per-hour basis, vice versa farm family labour can be offered for off-farm employment. To finance farm activities and to balance short-term liquidity shortages, farm agents can take up long-term and/or short-term credit. Liquid assets not used within the farm can be invested with a bank. Farm agents quit production and withdraw from the sector if equity capital is zero, the farm is illiquid, or if opportunity costs of farm-owned production factors are not covered.[7]

Farm agents are assumed to act autonomously and to maximise farm household income. For this, production and investment decisions are made simultaneously based on a recursive linear programme including integer activities (c.f. HAZELL and NORTON, 1986). From the solution of the linear programme, shadow prices of production factors can be derived. Farm decision making is myopic or boundedly rational (SIMON, 1955, 1956, 1996), that is, agents make decisions based on the information available to them, which can possibly even be wrong. Because of this, the decision problem of the model farms is highly simplified compared to that of real farmers in that strategic aspects are not included. Except for the price information on rents as well as product and input prices, individual farms in AgriPoliS do not know about other farms' production decisions, factor endowments, size, etc. On the contrary, unbounded rationality would imply that farms take account of all interactions between farms, and the technical and political framework conditions now and in future periods and include these into the individual decision problem.[8] Farm agents are also boundedly rational with respect to expectations. In the majority of cases, farm agents follow adaptive expectations. Merely policy changes are anticipated one period in advance and included into the decision making process.

New investments affect production capacities for the operating lifetime of the investment. This implies investment costs to be sunk. A farm agent is handed over to the generation after a given number of periods. In case of such a generation change, opportunity costs of labour increase. Accordingly, continuation of farming can be interpreted as an investment into either agricultural or non-agricultural training. Finally, farm agents differ not only with respect to their specialisation, farm size, factor endowment and production technology, but also with respect to the person of the farmer, and particularly with respect to managerial ability.

2.3 Representation of the spatial, technical and political environment

Land is an essential input for most kinds of agricultural production activities, be it for plant production, as fodder ground, or as manure disposal area. Hence, space is a factor that cannot be neglected if agriculture is concerned. Geographic Information Systems (GIS) provide a way for organising spatial data and assigning certain properties to space. A common way to organise

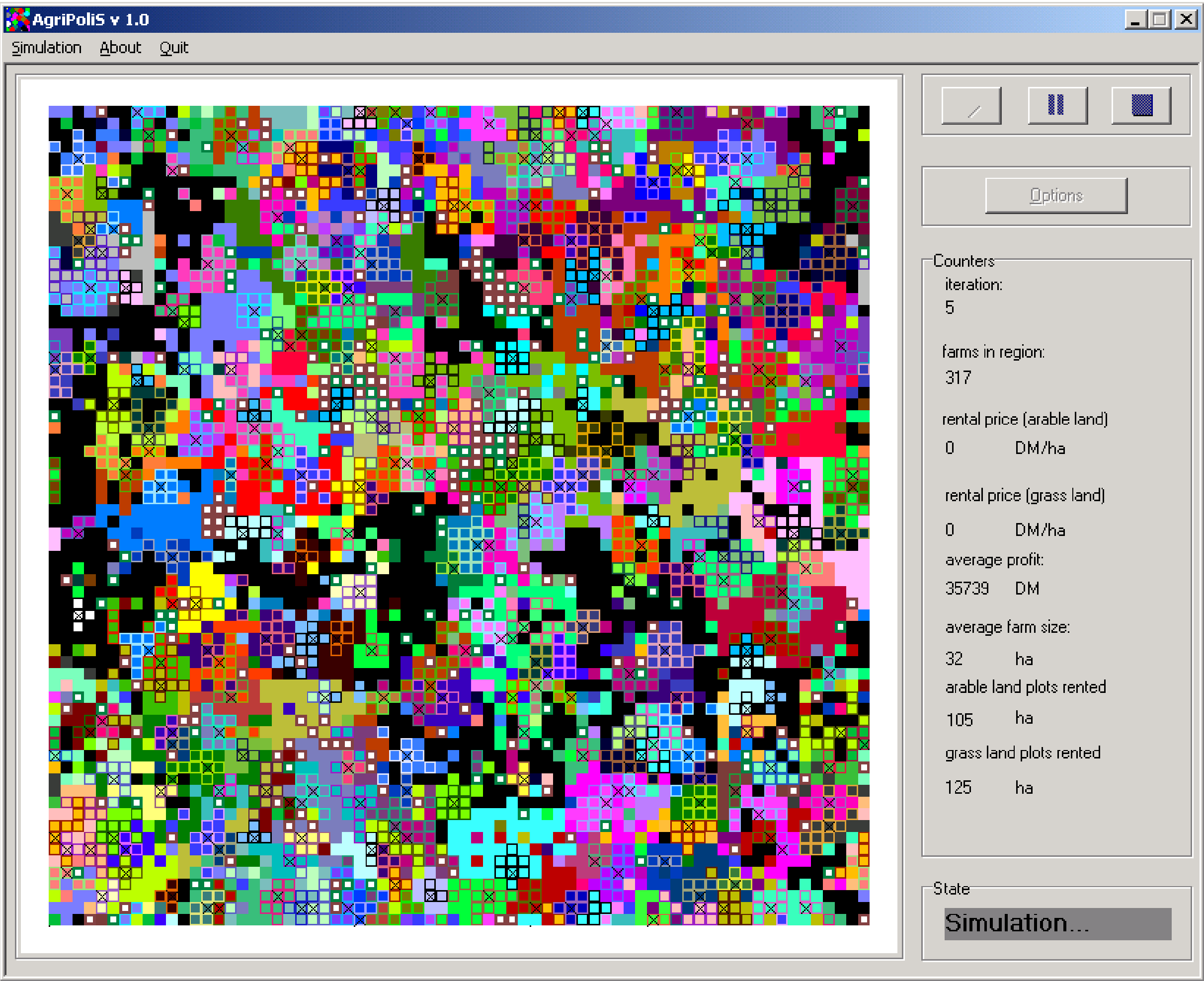
---

[7] As investment costs are assumed to be sunk, only opportunity costs for land and labour are considered.

[8] Currently, this cannot be implemented because of computational and methodological problems. For instance, there may not be a unique analytical solution to such a complex decision problem.

space in GIS is to define a grid of cells. A grid, or layer, categorises land with respect to attributes of the cells. For example, this could be the soil type, ownership, or ecological parameters like the nitrogen load. A GIS-like representation could also be used in the context of an agent-based model of agriculture to achieve an explicit spatial representation as some recent examples show (e.g. BERGER, 2004; PARKER et al., 2002). AgriPoliS, follows a more basic approach in that it does not implement a spatially explicit GIS in which the exact location of farms and land as found in a real region is modelled. Rather, in AgriPoliS is modelled in a stylistic way to implement some, but not explicit, spatial relationships. In the current version of AgriPoliS, space is represented by a set of cells/plots assembled into a grid to form a kind of cellular automaton (Figure 2).

Figure 2: An idealised grid representation of an agricultural region



Source: Own figure.

One individual plot represents a standardised spatial entity of a specific size that can take different states. In this idealised representation, all factors not directly relating to agriculture and land use (roads, rivers, etc.) were eliminated. The coloured cells represent agricultural land that is either grassland or arable land. Plots not used in agriculture are black. On some of the cells, farmsteads are located. They are marked with an X. The total land of a farm agent consists of both owned and rented land. All plots of land belonging to one farm agent are marked with the same colour; cells, which are owned, are surrounded by a box.

The technological environment is given by technologies of different vintages and technological standards. Over time, technology is assumed to underlie a constant technological progress created in the up-stream sector, but not on the farms themselves. Farm agents are assumed to benefit from technological progress by way of realising additional cost savings when adapting new technologies. The political environment represents the third building block of a farm agent's external environment besides space and technology. Agricultural (and environmental) policies affect the farm at different instances such as prices, stocking density, direct payments, or interest rates.

2.4 Agent interactions

The concept of interaction between agents is central to agent-based systems. Interaction takes place when two or more agents are brought into a dynamic relationship through a set of reciprocal actions. Interactions develop out of a series of actions of agents whose consequences in return effect the future behaviour of agents (FERBER, 1999). Interactions between agents take place either directly or indirectly, whereby an indirect interaction occurs through another agent.

At this development stage, agents in AgriPoliS interact indirectly by competing on factor and product markets. Interaction is organised by market agents that explicitly coordinate the allocation of scarce resources such as land or the transaction of products. Direct interactions between agents, for example for directly negotiating on rental contracts, are not considered at this stage of the model development.

In AgriPoliS, the land market is the central interaction institution between agents. In reality, the land market is of particular relevance, as farms very often cannot develop independently of land. In the case of Germany, livestock production is directly linked to the provision of land for fodder production or manure disposal. In this sense, land is a central prerequisite for farm growth. In Germany, farms predominantly grow by renting land additional. Because of this, AgriPoliS considers a land rental market, but does exclude a sales market for land. With regard to land, the ownership structure consists of family farms owning some land and external land owners. The latter are not modelled explicitly but farm agents rent their land. When AgriPoliS is run, land available for rent on the rental market stems from two sources: One is farms that have quit production and withdrawn from the sector, the other is land released to the market due to the termination of rental contracts.

In brief, the land allocation process works as follows.[9] To allocate this free land to farms, in AgriPoliS an iterative auction is implemented in which an auctioneer (market agent) allocates free plots to farm agents intending to rent additional plots of land. Farm agents' bids for particular plots of land depend on the shadow price for land, the number of adjacent farm plots and the distance-dependent transport costs between the farmstead and the plot. The auctioneer collects bids, compares them, and allocates free plots to farm agents. The auction terminates when all free land is allocated or if bids are zero. As both arable land and grassland are considered, the auction process alternates between these two land qualities.

2.5 Central modelling assumptions

As with every model, AgriPoliS rests on a number of assumptions. Two kinds of assumptions can be differentiated. On the hand, there are assumptions that represent central characteristics of an agricultural system. These form the corner stones of the model. BALMANN (1995) has listed the central characteristics of agricultural systems and structures, which shall be mentioned here again.

- The evolution of agricultural structures follows a dynamic process,

[9] For details see sections 5.2.1 and 6.1.

- Agricultural structures are path dependent, i.e. the history of the system determines its present state significantly and certain events are irreversible,
- For the most, decision making follows goal-oriented economic considerations,
- Certain activities, decisions and actions are indivisible,
- There are feedback mechanisms, particularly on the local scale, between the actions of individuals and between the results of individual actions.

On the other hand, there are assumptions that are model specific and are necessary to make the model operational and to keep it tractable and clear. Assumptions in particular concern farm behaviour, expectation formation, the definition of the planning period, and the representation of markets and the interaction with other sectors. These assumptions will be mentioned and discussed in this and later chapters where applicable.

3 IMPLEMENTATION OF THE CONCEPTUAL MODEL

3.1 Object-oriented structure and design

A natural way of transferring the conceptual framework presented above into a computer programme is to use an object-oriented programming language such as C++, Java, or Smalltalk.[10] Object-orientation provides away to break a problem into components. In brief, object-orientation describes a system of entities in terms of elements called *objects*. Objects consist of data (or attributes) and actions (or methods). The data represent the state of the object. The actions operate on an object's data and change it. For example, a farm agent's investment activity (action) changes the agent's capital endowment (data). In other words, an object provides functionality in terms of data and actions.

A programme built using an object-oriented design usually contains a large number of objects, of which many are the same. For example, in an agricultural structure all objects representing farms will be treated in basically the same way. When designing a computer programme such as AgriPoliS using objects it is therefore sufficient to describe the behaviour of sets of similar farms as a whole. A group of objects with the same data and actions is called a *class*. Because of this, it is actually more common and useful to define the functionality of classes instead of individual objects in the design of object-oriented computer programmes. To summarise, object-oriented programmes thus consists of a set of classes, he data associated with these classes and the set of actions the classes can be asked to undertake.

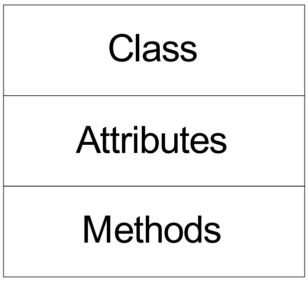
One key to understanding object-oriented design is to view the objects as living, intelligent entities of various types (REISS, 1999). They are living in the sense that their properties change over time. Objects are intelligent in that they can undertake actions and know how to perform them.

To visualise and document the design of an object-oriented computer programme it is convenient to use a standardised language such as the 'Unified Modeling Language' UML (BOOCH et al., 1999). UML simplifies the representation of complex software design. Accordingly, a representation of a class based on UML is given in Figure 3. The upper part the class representation shows the class name. The middle and lower parts list the attributes and the set of methods that the class can be asked to undertake.

---

[10] This section on object-oriented design is largely based on REISS (1999) who gives an intuitive introduction to object-oriented programming and design.

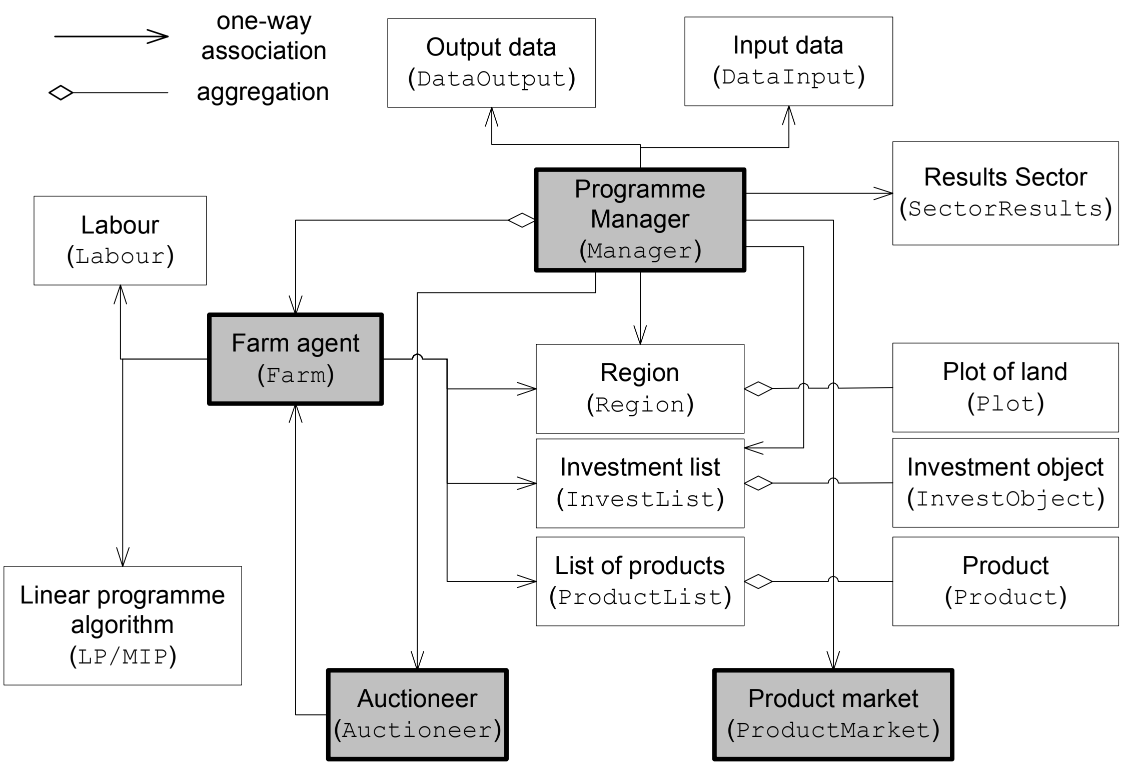
Figure 3: UML-representation of a class consisting of attributes and methods



Source: Own figure.

When building an object-oriented programme, one is first concerned with identifying the individual classes, then with defining the data and actions of these classes, and finally with describing the connection between classes. Figure 4 shows the object-oriented class design of AgriPoliS. Class names, as used in the C++ programme are in parentheses. The grey shaded classes are agent classes.[11]

Figure 4: Object-oriented design of AgriPoliS



Source: Own figure.

A 'navigability' connection between two classes denotes the flow of information between classes. For example, a farm agent needs to know where it is located in the region, but not vice versa. Aggregation denotes a collection. A region, for example, consists of a number of plots.

11 For reasons of clarity, the figure does not show attributes and methods. The complete model code can be provided by the author upon request.

For the model to perform its task, it is not necessary that all classes are related with each other and can evoke each other's methods. In the figure, lines are used to express different kinds of relationships between classes. In general, a line between two classes denotes an *association* relationship. Properties of this line, such as the arrowhead, are used to specify the character of the association further. For example, the relationship between classes `FarmAgent` and `LP/MIP` is implemented as a one-way association by using an arrow. This indicates that a `FarmAgent` object can invoke the methods of the `LP/MIP` object, but not the other way around. Likewise, a farm agent knows its location by querying the `Region` object to return the position of the farm in the region (`FarmAgent → Region`), but the reverse is not possible. Another type of association is *aggregation*, denoted by a diamond. For example, the line from `Region` to `Plot` starts with a diamond, which denotes an aggregation. In this case, the region contains a set of plots. Similarly, each list of production contains a set of products.

From the classes shown in Figure 4: Object-oriented design of AgriPoliS, four kinds of objects can be derived: Objects representing agents (`Farm, Auctioneer, ProductMarket`), objects representing production inputs and outputs (`Product, ProductList, Labour, InvestObject, InvestList, Plot, Region`), results and data management objects (`SectorResults, DataOutput, DataInput, LP/MIP`) and the `Manager` which controls the programme flow.[12] Accordingly, agent objects use the functionality embodied in input and output objects to achieve their respective goals. Results and data management objects offer some auxiliary functionality in that they provide optimisation methods on the one hand, and functions to summarise farm data on the other hand.

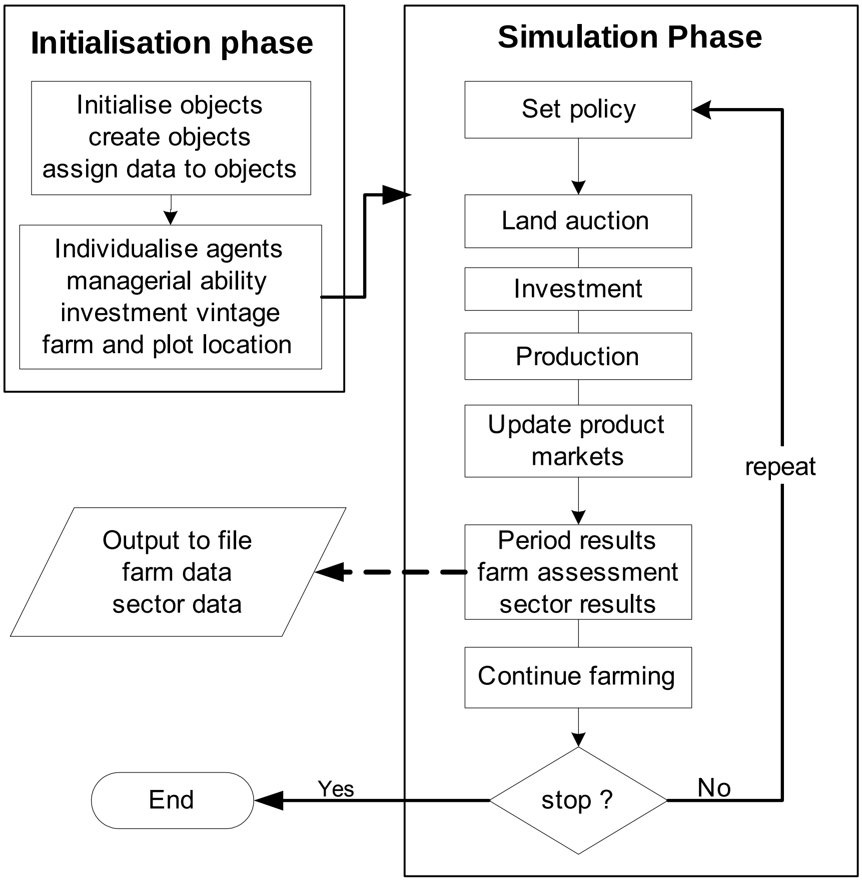
3.2 Model dynamics

Whereas Figure 4 presents the static structure of the AgriPoliS model, Figure 5 illustrates the dynamics which are implemented and controlled by the `Manager` objects. As can be seen, the `Manager` essentially includes two model phases, the initialisation phase, and the simulation phase. In the initialisation phase, the model structure, as described in section 2, is created. This includes the creation of objects based on the class definitions, and assigning values to the respective attributes of the various objects. The initialisation phase ends with further individualising farms with respect to attributes for which empirical data is not available or difficult to obtain.

Following the initialisation phase, the simulation phase starts with setting the political framework conditions that is valid during the subsequent simulation period. Following this, the `Manager` invokes the `Auctioneer` agent to carry out the land auction to allocate unused land to farm agents. After the land auction has finished, farm agents have the possibility to invest in new machinery, buildings, or equipment, and following this to produce using the available production factors. After production, the `Manager` invokes the `Market` agent to bring together production of all farm agents in the respective region and to determine a price for each type of product produced by the farm agents.

[12] As mentioned in section 3.2.1, the `Manager` can also be interpreted as an agent.

Figure 5: Model dynamics implemented in the Manager class



Source: Own figure.

At the end of each simulation period, farm agents assess their economic performance during that particular period. Based on this assessment and given prospective policy changes, the farm agents form expectations about the next production period to decide on whether to continue or stop farming. For this decision, farm agents take into account all possible adjustment options such as off-farm labour opportunities, selling excess quota, and terminating land rental contracts. Fixed assets cannot be disinvested due to the mentioned sunk cost assumption. Results for each individual farm agent and the sector as a whole are written to an output file. The simulation terminates when the number of specified simulation periods is reached.

4 INPUT AND OUTPUT OBJECTS

Input and output objects subsume all those objects that are necessary for agents to transfer inputs into outputs in the case of the farm agents or to organise a market. Each of these are described in the following.

4.1 Production factors

Production factors in AgriPoliS primarily concern the classical production factors land, labour, and capital, whereby the factor capital includes both money and assets for production.

4.1.1 Land

The spatial representation in AgriPoliS is organised by way of cells (see Figure 2), called plots (class `Plot`) of equal size. Taken together, the plots make up the entire region (class `Region`).

Plots differ with respect to three aspects: Land quality, usage structure, and ownership. Regarding land quality, AgriPoliS considers two qualities: Arable land and grassland. Land of either quality is assumed to be homogeneous. Regarding the usage structure, agricultural utilised area classifies as either managed land or abandoned land. And finally, at the outset of the model, agricultural utilised area is either owned by farm agents or rented. All land not owned by farm agents is assumed to belong to external land owners which are not explicitly modelled. The individual plots in AgriPoliS are characterised by a number of attributes defining the plot's state, its location on the grid of plots, and its location relative to the location of the farm interested in renting the plot or the farm agent managing the plot already. A plot of either land quality can take different states:

- No agricultural use;
- Abandoned land currently not managed;
- Grassland or arable land;
- Plot rented by farm agent *k;*
- Plot is farmstead;
- Plot is owned by farm agent *k*.

4.1.2 Labour

Labour is supplied in three forms (class `Labour`). The first is labour supplied by the farm family. The amount of farm family labour is derived from accountancy data; it is expressed in labour units.[13] Furthermore, farms can hire additional workers either on a fixed contract basis or on an hourly basis. Hiring fixed labour is treated as an investment for a period of one year. The total labour capacity is determined in the mixed-integer programme, where variable labour and fixed labour are activities.

In addition to hiring labour, farms can also offer their own farm family labour on the labour market. This offers the possibility for non-professional farming, on the one hand, and reducing the overall farm labour if necessary on the other. Corresponding to hiring labour, fixed and variable off-farm labour activities are introduced as activities in the mixed-integer programme.

4.1.3 Capital

To produce, a farm agent needs capital both in the form of liquid funds to pay running costs, and in the form of fixed asset capital (investments), which determine a farm agent's productive capacity.

Investments are introduced into AgriPoliS by way of an investment catalogue (class `Invest-List`). This catalogue depicts a list of investment objects containing investment possibilities and production technologies typical for the region under investigation. The investment catalogue is available to all farm agents and it provides the basis for investment decisions by the farm agents. The individual objects in the catalogue differ with respect to the type of investment (e.g. dairy, fattening pigs, machinery), as well as the size of the investment reflected in the production capacity. For each type of investment, the catalogue contains a variety of sizes. Differently sized objects affect a farm agent in three ways: First, the effect of a larger scale of production is reflected in lower average annual unit costs compared to an object of the same

[13] One labour unit corresponds to the annual labour input in hour provided by one worker.

type, but of smaller size. Second, larger investments are also considered to have lower labour requirements relative to smaller investments.

Third, over time, the technology underlying investment objects is assumed to improve, whereby larger investment objects are assumed to be technologically more advanced. Although technological change is not modelled explicitly by way of changing the technical coefficients of production, AgriPoliS nevertheless aims to mimic two effects of technically more advanced production technologies. On the one hand, AgriPoliS assumes that with every new investment, unit production costs of the product produced with this investment decrease. The extent of this cost-saving effect depends on the technical standard of the investment (see section on cost expectations).

Stated more formally, each investment object $I_{h,i,d}$ (h=1,…,H) to produce product i (i=1,…,I) is defined by the set of attributes in Table 1.[14] Maintenance costs are expressed as a percentage of total investment costs.

Table 1: Investment attributes

- ID-number
- Type of investment (d)
- Investment costs (€)
- Production capacity (heads or hectares)
- Maximum useful life (periods)
- Labour substitution (hours)
- Maintenance cost (% of investment costs)
- Technical change factor (%)

In particular this is the investment's type d (d=1,…,D), investment costs, production capacity, maximum useful life, labour substitution in hours, maintenance costs, and a factor representing the impact of technological change. Maintenance costs are expressed as a percentage of total investment costs.

The maximum time that an investment can be used in production is given by its useful life. Before any investment object has reached its maximum useful life, the object cannot be sold. Accordingly, an object's salvage value at the end of the useful life is zero such that it is non-tradable. This particular assumption has important consequences for the decision making of farm agents because it implies that investment costs are fully sunk once an investment is made. Because of this, depreciations not variable and treated as fixed costs in any case.

Capital required for production and investments is considered in three forms: Short-term credit, long-term credit, and liquid equity capital.[15] Short-term credit is taken up by farms in the case of short-term liquidity shortages. The amount of short-term credit is not explicitly limited but interest is higher than for long-term credit, which therefore sets a kind of natural limit for borrowing in the short-term.

Long-term borrowed capital can be used to part-finance investments. It is assumed that a maximum share $(1-v)$ of investment costs is part-financed with borrowed capital with the remaining share v representing the equity financed share. Borrowed capital for investment is

[14] For more clarity subscripts i, and d will be omitted in the following.

[15] Liquid equity capital is defined as total equity minus land assets minus equity bound in asset capital.

supplied by an annuity credit that runs for the entire useful life of the investment. The maximum amount of borrowed capital is also not directly restricted. Nevertheless, it is assumed that a farm only invests if the equity financed share of total investment costs does not exceed a minimum equity reserve threshold MR value given by

$$\sum_{l=1}^{L}(v \cdot A_l) \leq L + 0.7 \cdot LA + 0.3 \cdot \sum_{l=1}^{L} A_{ec,l} \quad \text{with} \quad L = EC_{t-1} - LA - \sum_{l=1}^{L} A_{ec,l} \tag{1}$$

That is, there is a limit on the maximum equity capital that can be used for investment. The limit is introduced to prevent putting the substance of the farm at risk.[16]

4.2 Production activities

Production activities in AgriPoliS are distinguished into livestock production (e.g. fattening pigs, turkeys), plant production activities (e.g. crops, sugar beets, grassland), short-term capital activities (e.g. short-term borrowing), short-term labour activities (e.g. short-term hiring), and 'additional' activities. Most livestock and plant production activities are consist of the production of marketable products. Exceptions are grassland production activities and silage maize, which serve as intermediate products for livestock production. Additional activities relate to those activities besides capital and labour which are needed to balance capacities in the short-run. This includes, for example, manure disposal, machinery contracting, or milk quota lease. Similar to investment objects, each individual production activity is characterised by a set of attributes (Table 2).

Table 2: Production attributes

- ID-number
- Production branch (e.g. sows for breeding, dairy production)
- Product produced with investment I_o of type d
- Price (€/unit)
- Variable unit production costs (€/unit)
- Price flexibility
- Price trend (% change per period)
- Support payment (direct payment) (€/unit)

In the simulation, products are managed by the farm agents in a product list that keeps track of the total units produced as well as the gross margins associated with each product. Product prices change in response to developments on product markets. Variable unit production costs are affected by technological change, on the one hand, and by the individual managerial ability of a farm agent.

[16] This means that 70% of land assets LA and 30% of total equity-financed fixed assets have to be covered by total equity capital EC_{t-1} at all times. The parameters 0.3 and 0.7 produced the most plausible results in a set of try-out simulations with AgriPoliS.

5 THE FARM AGENT[17]

To characterise the farm agent, it is useful to first describe why farm agents do what they do and based on what. That is, this section will first describe a farm agent's behaviour and the goal of its actions before describing the farm agent's actions.

5.1 Behavioural foundation

5.1.1 Farm planning

To model the behaviour of farms it is necessary to make assumptions about goals, expectations, managerial ability, and the variety of actions that a farm agent can pursue. AgriPoliS assumes each farm agent to maximise farm family household income in any one planning period. One planning period corresponds to one financial year. That is, a farm agent aims for maximising the total household income earned by farm family members either on the farm or outside the farm.[18] The action space given to farm family members is defined by on-farm factor endowments (land, labour, fixed assets, liquidity), the situation on markets for production factors and products, the vintage of existing fixed assets, technical production conditions, overall economic framework conditions (work opportunities outside the farm, interest rate levels, access to credit), and the political framework conditions.

In order to maximise household income, farm factor endowments, production activities, investment possibilities, and other restrictions need to be brought together and optimised simultaneously. A suitable setting for this is a mixed-integer optimisation problem, the solution to which gives the optimal combination of action possibilities subject to the given framework conditions. Figure 6 shows matrix of the optimisation problem.

In this scheme, investments and fixed labour are considered non-divisible. They are therefore introduced as integer activities. The set of constraints consists of on-farm production capacities, but some constraints also reflect political framework conditions, such as the set-aside requirement, the limit on livestock density, or the nutrient balance. In more formal terms the mixed-integer optimisation problem is expressed as

$$\begin{aligned} &\max\ Y^e(\mathbf{x},\mathbf{p^e},\mathbf{c},\mathbf{A},\mathbf{I},\mathbf{r},MP,D,RE,L,BC,IC,GL,AL,MF,\ldots) \\ &\text{with}\, Y^e = \mathbf{x}'(\mathbf{p^e}-\mathbf{c}) + IR + S + W - RE - MC - D - OV - TC - IC - HW \\ &\text{s.t.} \quad \mathbf{b} \geq \mathbf{x}'\mathbf{R} \qquad \text{with} \quad \mathbf{R} = (r_1,\ldots,r_I,\ldots,r_H,\ldots,r_J) \\ &\qquad\ \ \mathbf{x} \geq 0 \end{aligned} \tag{2}$$

This optimisation problem produces the vector q of shadow prices for scarce resources. Particularly the shadow price of land q_{Land} is of interest because it provides the basis for the production of bids in the land auction (see section 5.2.1).

[17] In this section, subscript *k* is omitted to increase clarity. All formulae concern one farm agent only.

[18] The assumption of household income maximisation is reasonable in the current version of AgriPoliS as it is applied to a region with only family farms, where the majority of the workload is done by unpaid farm family labour. If other organisational forms such as corporate farms would be considered, this particular assumption would probably need to be reconsidered to reflect potentially different goals of corporate farms.

Figure 6: Exemplary scheme of a mixed-integer programme matrix[19]

Mixed-integer programme		Short term loans/saving	Buy/sell variable labour	Hire contractor	Plant production	Livestock production	Set-aside land	Buy/sell manure	Buy/sell milk quota	Investment activities	Buy/sell fixed labour
		c	c	c	c	c	c	c	c	i	i
	Objective function	*Gross margin*									
Factor capacities	Liquidity (€)	x		x	x	x	x			x	x
	Min. equity capital reserve (€)				x	x	x			x	x
	Labour (h)		x		x	x	x	x		x	x
	Utilised agricultural area (ha)				x			x			
	Winter fodder (ha)					x					
	Livestock capacities (places)					x				x	
	Machinery (ha)			x	x		x			x	
Other restrictions	Organic N-balance (kg N/ha)				x	x					
	Rape seed max. (% of UAA)				x		x				
	Sugar beet max. (% of UAA)				x						
	Set aside (% of UAA)				x		x				
	Milk quota (litres)					x			x		
	Direct payments (€)				x	x	x				
	Stocking density (LU/ha)				x	x	x				

Notes: c=continuous activities, i=integer activities.

Source: Own figure.

5.1.2 General remarks about expectation formation

Production planning, investment, but also the decision to continue or quit farming is based on expectations about future developments of prices, costs, technologies, investment possibilities, and policies. In AgriPoliS, farm agents can form short-term expectations about the next planning period. However, farm agents are not capable of forming long-term expectations. With respect to all other future periods, they expect prices and costs to remain constant.[20] By doing so, dynamic effects resulting from expectations about the development of markets and

[19] Compared to highly differentiated and detailed farm-based linear programming models (e.g. KAZENWADEL, 1999; MÜLLER, 2002), the optimisation model in AgriPoliS is aggregated. In view of a very detailed representation of the farm organisation the chosen aggregation can be considered to be a rather crude simplification compared to the actual planning situation and question faced by real farms. However, with respect to the objective of AgriPoliS it is not the specific farming system which is of interest in this study but rather a basic representation of central organisational characteristics as well as financial/economic considerations.

[20] This assumption has some implications in particular for investment activity because farm agents make long-term investment decisions on the basis of short-term expectations. If farm agents would be able to articulate medium or long-term expectations, some investments probably would not be made. The introduction of long-term expectations might be desirable but currently it is limited by practical problems. It appears to be particularly difficult to consider short-term and long-term expectations simultaneously. The problem would be even more complex if expectations would also be made with respect to the behaviour of other farm agents.

demand developments are neglected. Farm agents also follow the same pattern of expectation formation, i.e. there is no differentiation between optimists and pessimists.

5.1.3 Price expectations

Regarding prices, farm agents follow adaptive expectations defined in terms of the weighted geometric average of actual and expected prices.[21] A farm agent bases all planning decisions on expected prices. This is obvious because actual prices are only determined at the end of a production period as a result of farm activity. The expected price of production activity i in period $t+1$ is determined as

$$p^e_{i,t+1} = (p_{i,t}{}^{\alpha} \cdot p^e_{i,t}{}^{(1-\alpha)}) \cdot \gamma_i{}^{-1} \text{ with } 0 \le \alpha \le 1 \text{ and } p > 0 \text{ for i} = 1,\ldots,\text{I} \tag{3}$$

The coefficient γ controls for a price trend of production activity i, whereby prices increase (decrease) if $\gamma < 1$ ($\gamma > 1$). In AgriPoliS the actual price and the expected price in period t are equally weighted, i.e., $\alpha = 0.5$.

5.1.4 Cost expectations

A farm agent also forms expectations about production costs. With regard to cost expectations, livestock and plant production activities are differentiated from the additional production activities.

For the group of additional production activities, the farm forms cost expectations in the same way than price expectation, however, without the price trend introduced for product prices. Accordingly, expected costs of additional production activities are calculated as the weighted geometric average

$$c^e_{i,t+1} = c_{i,t}{}^{\alpha} \cdot c^e_{i,t}{}^{(1-\alpha)} \text{ with } 0 \le \alpha \le 1 \qquad \text{for i} = 1,\ldots,\text{I}. \tag{4}$$

Cost expectations for livestock and plant production activities are determined in a different way in order to introduce the cost-saving impact of technologically more advanced production technologies. With respect to this, it is necessary to distinguish between plant production activities and livestock production activities.

As mentioned above, it is assumed that the technological standard of production technology improves with time. Thus, with every new investment into livestock production, the expected production costs $c^e_{i,t+1}$ of livestock production activity i produced with investment object I_o are computed as

$$c^e_{i,t+1} = c_{i,t} - f_{o,i} \cdot c_{i,t} \text{ with } 0 \le l < 1 \qquad \text{for i} = 1,\ldots,\text{I}, \tag{5}$$

whereby factor f represents the size of the investment. The factor is higher for larger investments.

---

[21] Unlike the more common definition as the weighted arithmetic mean, the chosen definition tones down expectations for period t+1 if expected prices and actual prices in period t differ (cf. BALMANN, 1995).

On the subject of plant production activities, cost savings can only be realised as a combination of larger machinery together with larger field sizes.[22] Expected costs of plant production activities $c_{i,t+1}^{e}$ are thus a function

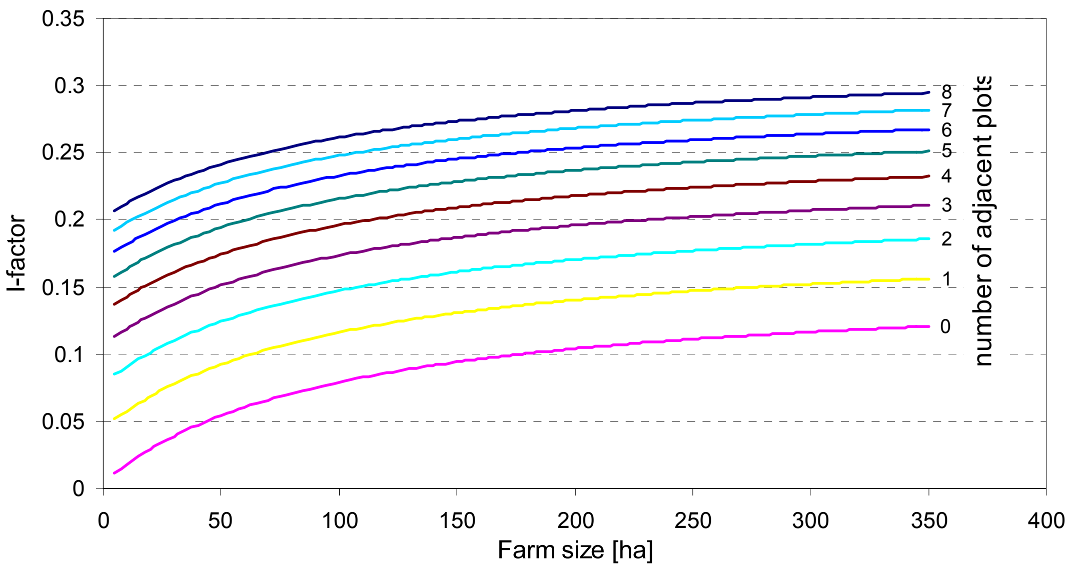
$$c_{i,t+1}^{e} = c_{i,0} - l \cdot c_{i,0} \text{ with } 0 \le l < 1 \qquad \text{for i} = 1,\ldots,\text{I} \tag{6}$$

of costs at the outset of the simulation adjusted by a factor l which is a function of the average number of adjacent plots and the size of the farm. The factor l thus captures the effect of larger field sizes. It is defined as

$$l_t = \left[1 - \frac{0.15}{1 + 100/Z}\right] \cdot \left[1 - \frac{0.45}{1 + 100/(10 \cdot AP_t + 1)}\right]. \tag{7}$$

Figure 7 shows values of l for different farm sizes and average numbers of adjacent plots. Accordingly, a farm agent with initially little and scattered land can realise large cost savings if it considerably increase its acreage. The potential cost effect is much lower if a farm agent's acreage is already high and if the plots are in the neighbourhood.

Figure 7: Expected cost savings for machinery investments depending on farm size and the average number of adjacent plots



Source: Own figure.

5.1.5 Expectations about policy changes

When forming expectations about the next planning period, policy changes have to be taken into account as well, particularly if changes are expected to be strong. It is assumed that a farm agent knows about major policy changes one period before the policy becomes effective. This influences decision making primarily when it comes to evaluating the farm agent's profitability

[22] KUHLMANN and BERG (2002) quantify the cost difference between a 1 ha plot and one of 60 ha at 250 €/ha which corresponds to about a third of the current revenue for wheat.

at the end of a planning period (see section 5.2). In AgriPoliS, no general expectation formation with regard to policy changes is implemented. Rather, depending on the policy setting to be simulated, specific assumptions and expectations have to be formulated and introduced into the model.

5.1.6 Managerial ability

In real world agriculture, the economic performance of farmers can differ substantially even if they operate under more or less the same production conditions using the same production technologies. These differences in the economic performance of farmers are often attributed to differences in the managerial ability of farmers (NUTHALL, 2001; ROUGOOR et al., 1998). Managerial ability can be understood as the ability of a farm agent to use its technology to realise all potential cost savings. Accordingly, production costs are lower if managerial ability is higher. In AgriPoliS, the managerial ability of a farm agent is introduced by a factor m, which is drawn randomly from a uniform distribution at start-up. The factor affects production costs of all products in the initial period according to

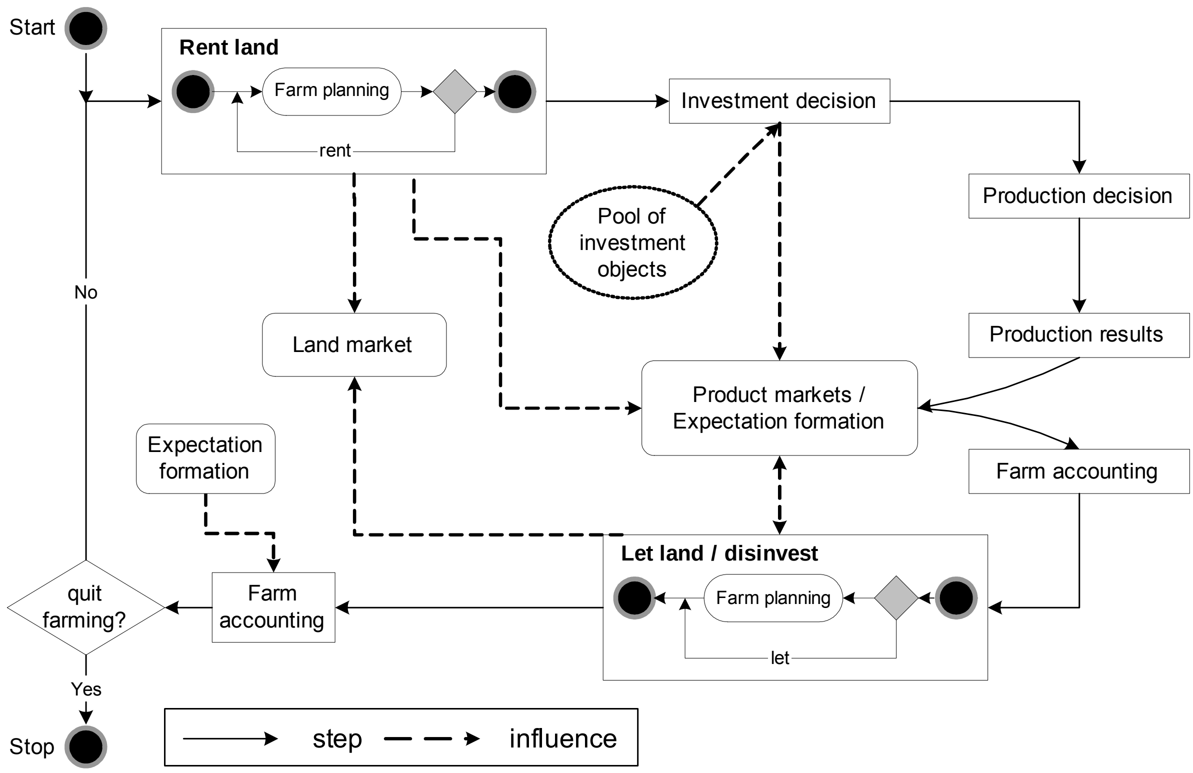
$$c_{i,0}^{new} = m \cdot c_{i,0} \quad . \tag{8}$$

In the current version of AgriPoliS, farm agents cannot learn and improve managerial ability.

5.2 Farm actions

During one planning period, a farm agent passes through a number of steps, shown in Figure 8. Each step describes an action.

Figure 8: Course of events in one planning period for a single farm agent



Source: Own figure based on BALMANN (1995).

Based on the figure, the most important actions undertaken by a farm agent are renting land (renting additional land and disposing of unprofitable land), investment, production, farm accounting, and the decision whether to quit farming or stay in the sector.

5.2.1 Renting land

As mentioned at several points during this chapter, the land market is of particular relevance. As farms predominantly grow by renting land, AgriPoliS only considers a land rental market. As shown in Figure 2, in AgriPoliS, all farmland is categorised as plots of the same size. Plots are not divisible, and their size is fixed during one simulation run. Accordingly, the size of a plot defines the smallest unit by which farm acreage can change. Initially, each farm agents is endowed with a certain amount of land consisting of owned and rented land. Regarding the duration of a rental contract, no formal contract length is introduced in AgriPoliS. Instead, it is assumed that a farm agent can terminate unprofitable rental contracts at the end of each planning period. Rental contracts for profitable plots remain valid.[23] Accordingly, land is available for rent either because a farm agent withdraws entirely from agriculture or because rental contracts are terminated.

In each period, land available for rent is allocated to farms in an iterative auction. In order to be eligible for renting one additional plot a farm agent is asked by the auctioneer agent to make a bid for a particular plot in the region. Assuming that transport costs and the exploitation of economies of size for machinery (see section 5.1) influence the renting behaviour, a farm agent aims at renting a free plot which is closest to the farmstead and next to other plots belonging to the same farm agent. The maximum price, or bid, $BID_{y,z}$ for plot $P_{y,z}$ of either land quality is a function of both transport costs $TC_{y,z}$ between the farmstead and the plot, and the number of adjacent plots T. It is defined as

$$\begin{aligned}
BID_{y,z} &= (q_{Land} - TC_{y,z}) \cdot \beta + T \cdot \delta && \text{for} \quad 2 < T \leq 8 \\
BID_{y,z} &= (q_{Land} - TC_{y,z}) \cdot \beta + \delta && \text{for} \quad 0 < T \leq 2 \text{ with } 0 < \beta < 1. \\
BID_{y,z} &= (q_{Land} - TC_{y,z}) \cdot \beta - \delta && \text{for} \quad T = 0
\end{aligned} \tag{9}$$

Parameter β reduces the bid to reflect other costs associated with leasing land such as taxes, administrative costs, labour costs and fees as well as the farm agent's additional rent derived from renting this plot. Accordingly, β represents the proportion of the shadow price of an additional plot remaining with the farm agent. The higher the value of β–and therefore the higher the bid – the larger the proportion of the shadow price of land that is eventually passed on to the land owner. A higher bid also increases the probability of a farm agent to receive the plot it wishes. In this respect, the difference $q_{Land} - \beta \cdot (q_{Land} - TC_{y,z})$ can also be interpreted as a kind of security mark-up. Moreover, if the desired plot is next to other farm plots, a surcharge δ is added to the bid. If the bid is highest compared to other farms, the farm agent receives the plot.

An obvious problem with this procedure is related to the fact that the shadow price of land is only determined for one additional plot at a time. In fact, because of the indivisibility of investment options, the shadow price for land derived from the optimisation model may po-

[23] This assumption is quite different from rental contracts in reality, which usually involve a long-term commitment for a number of years.

tentially change rapidly if calculated for more than one plot at a time. For that reason, it would be reasonable if farm agents could bid for more than one plot at a time. This poses computational difficulties, though, as different bundles of plots would need to be tested to derive the maximum shadow price from a combination of plots. Therefore, in addition to the shadow price for only one plot the average shadow price for renting eight plots at a time is calculated. The maximum shadow price of one additional plot and of eight additional plots is then taken as the basis for the bid.

Similar considerations apply when a farm gives up rented land to increase its overall profitability (see section on farm accounting).[24] In this case, a farm would give up the rented plot $P_{y,z}$ if the shadow price does not cover the plot's costs consisting of the rent $R_{y,z}$ and transport costs $TC_{y,z}$, that is if

$$q_{Land} < \max_{y,z} (R_{y,z} + TC_{y,z}) .^{25} \tag{10}$$

After giving up a plot, the farm recalculates the shadow price of land. The procedure is repeated until the shadow price of land is at least equal to the costs of a plot. Unless a farm agent withdraws from agriculture altogether, it is not possible to let owned land in order to be rented by other farm agent.

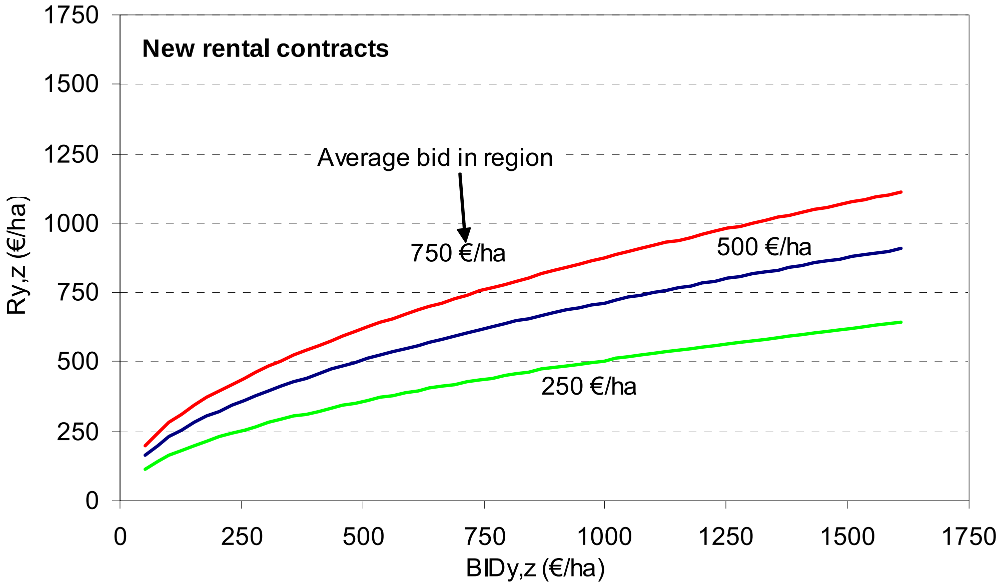
In AgriPoliS, the rent paid for a plot does not exactly correspond to the bid given in the land auction. This has two reasons. The first is that shadow prices can vary significantly between farms. Hence, rents would differ significantly between farms, which would affect the farm agent's competitiveness. The second reason is that this does not correspond to reality. In reality most new rental contracts include a passage that places rents in the context of an average regional rent. To reflect this, the actual rent paid for a newly rented plot is calculated as

$$R_{y,z} = \sqrt{BID_{y,z} \cdot \overline{R}} , \tag{11}$$

i.e., is it derived from the weighted geometric average of the bid $BID_{y,z}$ given in the auction and the average regional rent $\overline{R}$ with equal weights. Figure 9 shows this relationship graphically.

[24] Here, the number of adjacent plots is not taken into account.
[25] Adjacent plots are not considered when rental contracts are terminated.

Figure 9: Rent adjustment for new rental contracts



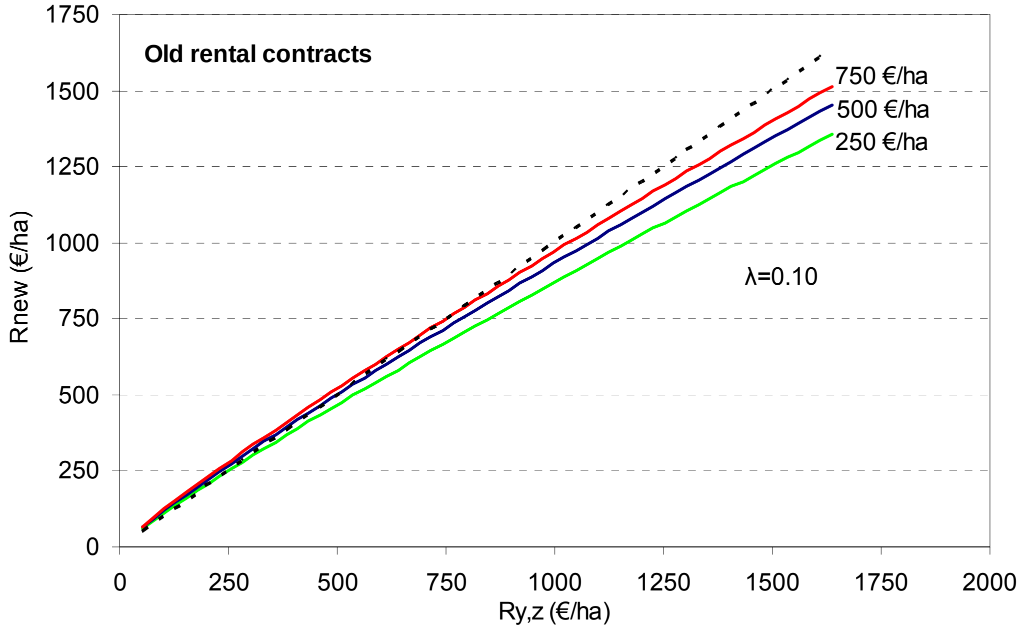
Source: Own figure.

As it is often the case in reality, also the rent fixed in older rental contracts is adjusted. Frequently, such an adjustment is due to strong product price changes, policy changes, or changes in the regional reference rent. In AgriPoliS, the adjusted rent $R_{y,z}^{new}$ for old contracts is the weighted geometric average of the average rent in the region and the previous rent of the plot

$$R_{y,z}^{new} = R^{\lambda} \cdot R_{y,z}^{(1-\lambda)}, \tag{12}$$

whereby the weight λ is given by the share of newly rented land in the entire region. Depending on λ and the average regional rent, the adjusted rent develops close to the initial bid. This is plotted in Figure 10.

Figure 10: Rent adjustment for old rental contracts



Source: Own figure.

5.2.2 Investment

Farm investment activity is typically concerned with the purchase of machinery, buildings, facilities, and equipment. As investment and production are mutually interdependent, they are considered simultaneously in the mixed-integer planning programme presented in section 5.1

Investments in AgriPoliS take place in two steps, investment planning and the actual investment. In the first step, the farm carries out planning calculations based on the farm planning problem presented in section 0. During the planning calculations, be it in the context of renting land or for production, a farm agent takes investment opportunities into account. However, during all planning calculations the agent does not invest in real terms but plans 'as if' he invested, i.e. production capacities are not actually changed. The number, kind, and combination of investments are not restricted. In principle, a farm agent only invests in one object or a combination of objects if the expected average return on investment, determined in the farm-planning problem, is positive, i.e. if total household income increases. For investment-planning purposes, all expenditures and payments related to an investment are distributed equally over the investment's useful life and considered in the optimisation. Accordingly, the average annual costs AC_h of investment $I_{h,i}$ considered in the objective function of the farm-planning problem are calculated as

$$AC_h = A_h \left[(1-v) \cdot CRF_{i_{bc},N_h} + \frac{v}{N_h} + MC_h \right] \tag{13}$$

Maintenance costs MC_h are expressed as a percentage of total purchase costs. The average annual opportunity costs of equity capital bound is determined as

$$A_h \cdot v \cdot f, \qquad \text{with} \quad f = \frac{(1+i_{ec})^{N_h}}{(1+i_{ec})^{N_h}-1} - \frac{1}{N_h \cdot i_{ec}}. \tag{14}$$

Only in the second step, based on the planning calculations, the actual investment activity takes place (see Figure 8**)** resulting in a change of production capacities. After investment, depreciation and repayment are determined as shown in Table 4.

5.2.3 Production

Each farm agent is assumed to optimise production in any one planning period subject to available production capacities using the planning approach described in section 5.1 above. All production activities enter the optimisation as continuous activities. That is to say, products are assumed to be fully divisible.

In addition to fixed assets (buildings, machinery, equipment), production requires liquidity to cover running costs in the short-run. Products produced continuously throughout the year (mostly livestock production) have a constant demand of working capital, which in AgriPoliS is defined as liquid assets. Other products such as crops are seasonal products and therefore require working capital only during parts of the year. To overcome short-term liquidity shortages, farm agents can take up loans to finance working capital.

5.2.4 Farm accounting

The financial year of a farm agent ends with an annual financial statement. This statement produces indicators on incomes and profits, the stability and financial situation of the farm agent, and the remuneration of fixed factors. Table 3 shows a list of selected variables in the financial statement.

Table 3: Indicators calculated in the financial statement

Indicator (end of period t)	Calculation
Profit (farm income) (t) =	Gross margin + Interest on working capital + Subsidies - Rent paid - Current upkeep of machinery and equipment - Depreciation - Farming overheads - Transport costs - Interest paid - Wages paid
Household income (t) =	Profit + Off-farm income
Farm net value added (t) =	Profit + Rent paid + Interest paid + Wages paid
Equity capital (t) =	Equity capital (t-1) + (Household income – Withdrawal)

Change in equity capital is an indicator of a farm agent's economic stability. A farm is economically more stable the higher the equity-debt ratio of the farms, i.e. the higher the share of equity capital in total capital. Consequently, it would be reasonable for a farm to stop farming if equity capital is less than zero. In this case, all own resources, which could be used, for example, as credit security are used up.

Accumulation of equity capital is the result of balancing total farm income with living expenses. In AgriPoliS, the equity capital stock increases because total household income is greater than withdrawals. Regarding withdrawals, it is assumed that each family labour unit working on the farm consumes at least $WD_{\min}$ per year. A share ε of the remaining farm household income after deducting $WD_{\min}$ is consumed in addition to the minimum withdrawal. The remaining share $(1-\varepsilon)\cdot(Y-WD_{\min})$ is then charged to the farm agent's equity capital. Table 4 shows this.

Table 4: Definition of variables used in financial statement (selection)

Variable (at end of period t)	Definition
Equity capital	$EC = EC_{t-1} + Y - WD$
Withdrawal	$WD_{\min} \le WD \le (Y - WD_{\min})\cdot\varepsilon + WD_{\min}$ with $0 < \varepsilon \le 1$
Gross margin agricultural products	$GMA = \mathbf{x}'(\mathbf{p}-\mathbf{c})$
Interest on borrowed capital	$IC = \mathrm{f}(BC, i_{BC})$
Repayment	$RP = (1-v)\sum_{c=1}^{S}\left[A_c\cdot(1+i_{bc})^{(n_c-1)}\cdot(CRF_{i_{bc},N_c} - i_{bc})\right]$
Long-term loans	$BC = BC_{t-1} - RP + BC^{new}$
Depreciation	$D = \sum_{c=1}^{S}\left[A_c\cdot(1+i_{bc})^{(n_c-1)}\cdot(CRF_{i_{bc},N_c} - i_{bc})\right] + \sum_{c=1}^{S}\left[A_c\cdot(1+i_{ec})^{(n_c-1)}\cdot(CRF_{i_{ec},N_c} - i_{ec})\right]$
Farming overheads	$OV = \gamma\cdot GMA$ with $\gamma \le 1$
Current upkeep (maintenance)	$MC = \sum_{c=1}^{S} MC_c$
Rent paid	$RE = \sum_{y}\sum_{z} R_{y,z}$
Transport costs	$TC = \mathrm{f}(DI_{y,z})$
Liquidity[a)]	$L = EC_{t-1} - LA - A_{ec}$
Interest on working capital	$IR = i_{ec}\cdot L$

Notes: [a)] Liquidity is updated throughout the accounting year whenever the total equity capital stock changes due to investment or disinvestment.

Lasting farm profitability requires that all farm-owned production factors (own land, family labour, liquid equity capital, and quota) receive an adequate payment when used on-farm. To assess farm profitability, all on-farm production factors have to be valued at their opportunity costs (Table 5). Since costs of fixed assets are assumed to be sunk, they are not considered in this calculation. In the case of handing over the farm to the next generation, opportunity costs of labour are also higher if a farm is handed over to the next generation. This reflects the comparable industrial salary a successor could potentially earn if he/she would not take over the farm. Accordingly, a successor would only take over the farm if the farm were able to generate income that is at least as high as the opportunity costs.

A decision on whether to quit is necessary subject to the expected household income in future periods. As mentioned above, the planning horizon of a farm agent is one period. Hence, the calculation of expected household income takes account of investment possibilities and off-farm employment possibilities in the next period. Moreover, expected household income rests on the assumption that a farm agent's land endowment does not change. The resulting expected household income is contrasted with the opportunity costs of all on-farm production factors.

Table 5: Opportunity costs of production factors

Factor…	valued at…
Farm family labour	Off-farm income
Labour of farm successor	Comparable industrial salary
Working capital	Long-term savings rate
Owned land	Average regional rental price
Milk quota	Quota price

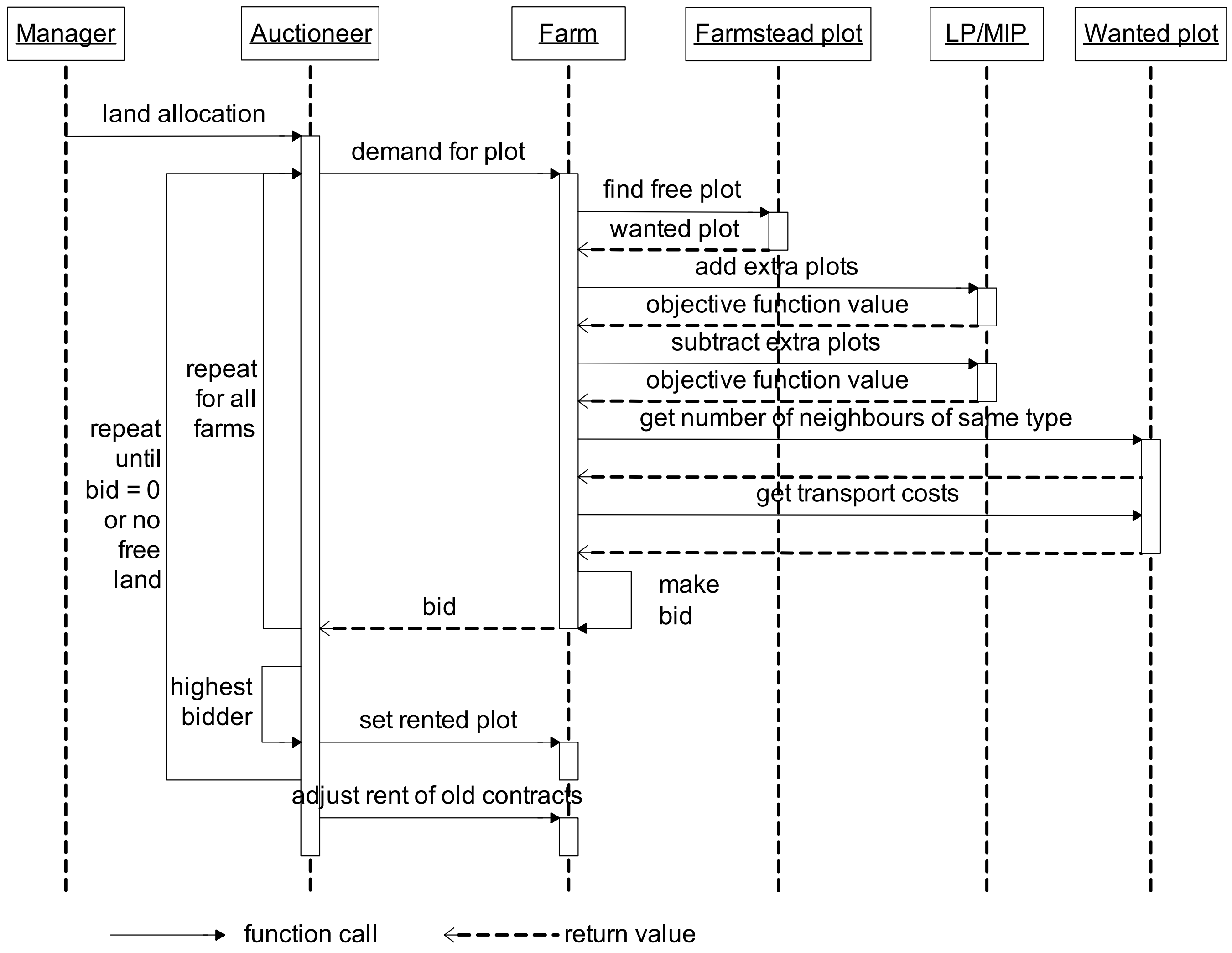
If expected household income does not cover opportunity costs, it is rational for the farm to quit and use all production factors outside the farm. This decision rule defines a very clear threshold between quitting and staying. In some instances, it may be reasonable to blur this threshold, for example, by introducing a tolerance margin in which farms stay in business despite of higher opportunity costs.

6 FACTOR MARKET AGENTS

6.1 Land auctioneer

Compared to a farm agent, the auctioneer is a very basic kind of agent. The auctioneer to coordinates the auction of free plots by collecting bids from farm agents; it then compares the bids, and finally allocates a free plot to the highest bidder. The auctioneer acts on behalf of land owners who are not engaged in farming, but receive all rent payments. The exact auction process is illustrated in Figure 11 using UML notation. According to this figure, the order of events is the following: Triggered by the `Manager` class, the auctioneer carries out an iterative auction of free plots. It does so by asking each farm agent intending to rent additional land to produce a bid for one plot. As discussed in section 5.2.1, the farm does so by first searching for a free plot closest to the farmstead. It then determines a bid for that plot based on a combination of the shadow price of land, the number of plots adjacent to the desired plot, and transport costs. Following, the auctioneer ranks the bids and allocates the desired plot to the highest bidder. As farm agents can only bid for one plot at a time, the bidding procedure continues until all plots are allocated or the highest bid is zero. In a final step, the auctioneer determines the actual rental price that is to be paid for the plots just allocated. In addition to setting the price for new rental contracts, the auctioneer also initiates the price adjustment of old rental contracts by applying the rent adjustment procedure shown in section 5.2.1. This ends the land allocation procedure.

Figure 11: Sequence diagramme of the land auction



Source: Own figure.

6.2 Product market

The product market agent determines a market price for all produced outputs in any one period. For this, the market agents make use of a number of price functions. The demand function for agricultural products in AgriPoliS assumes neither a fully elastic nor a fully static demand. Analogously to the function for gross margins developed in BALMANN (1995) it is assumed that for most products of products i the price in period t is a function

$$p_{i,t} = p_{i,0} \cdot \gamma_i^{-(t+1)} \cdot \left(\frac{\sum_k X_{k,t}}{\sum_k Z_{k,t}} \right)^{-b_i} \text{ with } k = 1,\ldots,K, \quad (15)$$

where $p_{i,0}$ denotes the initial price of product *i* at the outset of the simulation (period t=0), the coefficient γ_i controls for a price trend over time, and the last term allows for price variation in depending on the cumulative quantities produced by *K* farm agents. The parameter $b_{i,t}$ represents price flexibility which is equivalent to the inverse demand elasticity (cf. BALMANN, 1995).

The price function differs for selected products. In particular this is:

- *Piglet production:* Piglets are assumed to be used as intermediate inputs in fattening pig production. For this reason, the total quantity of piglets produced is reduced by the quantity of piglets used for fattening pig production.[26]
- *Milk quota:* Since the year 2000, prices for milk quota in Germany have been determined in quota auctions. Implementing such an auction would be a complex matter (comparable to the land auction). Regarding quota, AgriPoliS therefore implements a highly simplified quota market in that it reflects only the results of quota auctions. In principle, farms can buy and sell quota indefinitely. But, to keep milk production within realistic limits, the price of quota is related to a regional reference quota 27 If milk production is above (below) the regional reference level plus a 10% tolerance, the quota price rises (falls) by a given percentage. The quota market as implemented in the model resembles a quota leasing market. To prevent quota from leaving the region, the marginal revenue of selling quota is less than the marginal revenue of buying additional quota.
- *Manure trading:* Regarding manure trading, farm agents generally pay to dispose of excess manure, on the one hand. On the other, farm agents receive payments for taking excess manure up to a given limit. Manure trading is not limited to the region. That is why in the simulation there may be more farms taking up manure than farms disposing of manure and vice versa. Similar to the market for milk quota, the price of disposing manure rises the more excess manure is offered.

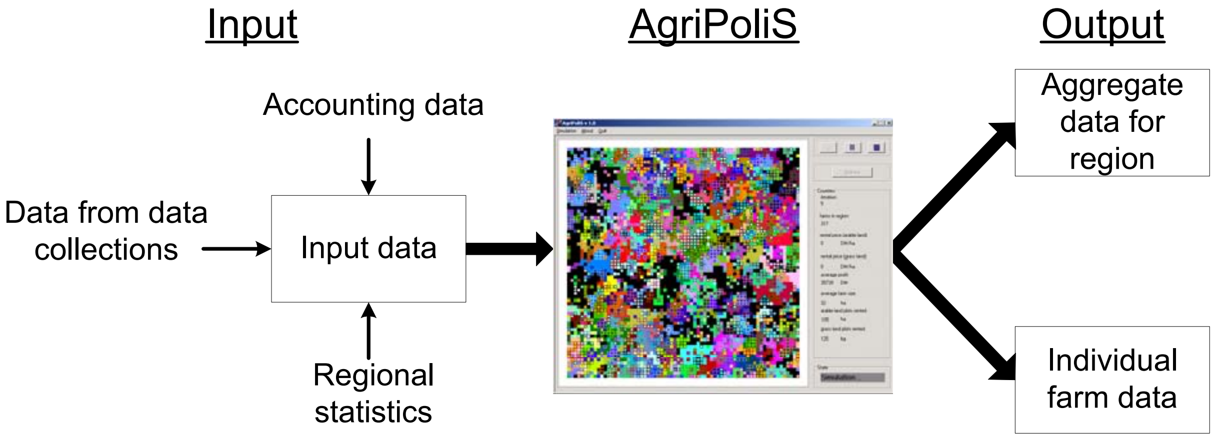
[26] At the current development stage, there is no interdependence between the price of piglets and the gross margin of pig fattening.

[27] The regional reference quota is calculated as the total number of dairy cows in the region to be modelled times the average milk yield in that region. A tolerance range of ±10% around the regional reference quota is assumed, so that it does not function as the exact threshold value for price changes.

7 DATA INPUT, RESULTS PREPARATION AND DATA OUTPUT

AgriPoliS has an interface to a spreadsheet file that includes data on the regional agricultural structure to be studied to initialise the model. The file contains data on individual farm agents (family labour, machinery, buildings, production facilities, land, production quota, liquid assets, and borrowed capital) as well as regional data (number of farms, farm types, total land). Figure 12illustrates the procedure of reading data into AgriPoliS in a schematic way.

Figure 12: Schematic representation of AgriPoliS input and output



Source: Own figure

On the input side, data – broadly speaking–input consists of farm accountancy data, regional statistics, and stylised data on technical coefficients, prices and costs. On the output side, AgriPoliS compiles aggregate data at the sector level (class `SectorResults`), on the one hand, and individual farm data, on the other hand. More specifically, data output at sector level and at farm level (class `DataOutput`) include data listed in appendix. Based on these indicators it is possible to draw conclusions with respect to production, economic performance of farms, production intensity, income distribution, and farm structure.

8 DISCUSSION AND CONCLUSIONS

This paper presented AgriPoliS, an agent-based model of regional agricultural structures. The set-up of AgriPoliS concentrates on modelling core components of family-farm dominated agricultural structures: Farms, product and factor markets, land as well as interactions between them. Inevitably, AgriPoliS rests upon many specific assumptions about agent behaviour, interactions between agents and parameters. Because of this, results and possible consequences ought to be interpreted and questioned against the assumptions made. For example, individual farm agents' sole objective is to maximise farm household income in addition to a very limited foresight of one period. Because of this, farm agents make decisions based on income expectations about the next period and do not account for changes in following periods. Assumptions are necessary to keep the model tractable, i.e., to make it computable and to ensure the co-ordination of agents. Although they should be carefully chosen, assumptions are always subjective in nature. Nevertheless, simulations of the reference scenario show plausible results compared to actual empirical observations and economic reasoning (see e.g. HAPPE and BALMANN, 2003; HAPPE and BALMANN, 2002; BALMANN et al., 2002).

The subjective nature of assumptions equally applies to the decision on the definition of core components of agricultural structures. Unavoidably, many other influencing factors that may be regarded important (by others) have been left out and not taken into consideration. For example, one could envisage to extend the model by considering companies along the process and value chain. Besides the definition of core model components, the definition of adjustment possibilities defined in AgriPoliS can be considered relatively narrow, in particular, as alternative production activities are defined exclusively based on typical production activities undertaken in the past (e.g. intensive livestock production or crop production). Moreover, real-world adjustment reactions such as possibilities to merge farms or co-operative resource use of farms were not considered.

Hence, with respect to further extension, a dilemma opens up. On the one hand, there is the attempt to find a good, precise and valid representation of real agricultural structures that includes important phenomena and components of the system. On the other hand, there are limits set by the complexity of a respective model. Although AgriPoliS maps basic components and adjustment reactions (but by far not all), the model itself has reached a level of complexity and specificity that makes it increasingly difficult to comprehend the implications of the model and to connect causes and effects. Further extensions may bear the danger that the model becomes so complex that it cannot be comprehended in itself is of no explanatory use (HANNEMAN and PATRICK, 1997). Hence, authors writing on simulation generally ask for models to be as simple as possible (e.g. BANKES, 1993; HANNEMAN and PATRICK, 1997; MANSON, 2002). In addition, time restrictions have to be considered. This relates to the computing time necessary to simulate a region over a specified number of periods and to the time devoted to model development and validation. The actual modelling and calibration is even more time consuming.

A lesson learned with regard to modelling structural change in agriculture is that as much as structural similarity between the model and reality is desirable, the modeller needs to be able to communicate the model, its assumptions, limitations and results, openly to an audience consisting of colleagues, knowledgeable experts, students and policy makers. This is mostly relevant because formal validation procedures cannot be applied in a straightforward manner to agent-based simulation and certain assumptions such as size effects have been a subject of heavy disputes among experts. So, critical discussion and exchange also represent a part of the validation process.[28]

Nevertheless, simulations with AgriPoliS and its precursor show results which are comparatively robust to parameter variations. Although the sensitivity analyses represented only a limited attempt at investigating the behaviour of AgriPoliS in a formal manner, the obtained results are in line with results obtained from simulation experiments carried out before this study using AgriPoliS or precursors of AgriPoliS. Moreover, results fit empirical observations such as slow structural change, persistently unexploited economies of scale, and income disparities (BALMANN, 1999).

To conclude, a model such as AgriPoliS offers many opportunities to look at the dynamics of agricultural structural change from new and different perspectives using a range of analysis methods. AgriPoliS, therefore, can be considered a promising tool for further policy analysis. To overcome the limitations posed by complexity, modellers will have to carefully extent AgriPoliS and conducts intensive tests periods at each new development step. This also extends to the implementation of different policy scenarios. Overcoming the shortcomings of

[28] These challenges are not solved by the steady increase in computing capacity. More computing power might shift problems related to the computability of complex models. However, ever powerful computers cannot solve problems relating to cognitive capacities of the modeller and the audiences as well as the fact that complex models are prone to errors. Finally yet importantly, data availability becomes restrictive the more differentiated the models become.

complex simulation models will depend to some extent on further progress in information technology, methodological progress, the resourcefulness of its users, and continuous training of future researchers.

REFERENCES

ARTHUR, W. B (1989): Competing Technologies, Increasing Returns and Lock-In by Historical Events, *The Economic Journal*, *99,* pp. 116-131.

ARTHUR, W. B., DURLAUF, S. N., LANE, D. (eds.) (1997): The Economy as an Evolving Complex System II, *SFI Studies in the Sciences of Complexity, Vol. XXVII,* Addison-Wesley, Redwood City.

BALMANN, A. (1995): Pfadabhängigkeiten in Agrarstrukturentwicklungen – Begriff, Ursachen und Konsequenzen, Duncker und Humblodt, Berlin.

BALMANN, A. (1997): Farm-based Modelling of Regional Structural Change: A Cellular Automata Approach, *European Review of Agricultural Economics, 24(1),* pp. 85-108.

BALMANN, A. (1999): Path Dependence and the Structural Development of Family Farm Dominated Regions, in: IX European Congress of Agricultural Economists Organized Session Papers, Warsaw/Poland.

BALMANN, A., LOTZE, H., NOLEPPA, S. (1998a). Agrarsektormodellierung auf der Basis 'typischer Betriebe'. Teil 1: Eine Modellkonzeption für die neuen Bundesländer, *Agrarwirtschaft, 47(5),* pp. 222-230.

BALMANN, A., LOTZE, H., NOLEPPA, S. (1998b): Agrarsektormodellierung auf der Basis 'typischer Betriebe'. Teil 2: Auswirkungen der "Agenda 2000" auf die Landwirtschaft in den neuen Bundesländern, *Agrarwirtschaft, 47(6),* pp. 251-258.

BALMANN, A., ODENING, M., WEIKARD, H.-P., BRANDES, W. (1996): Path-Dependence without Increasing Returns to Scale and Network Externalities, *Journal of Economic Behavior and Organization*, *29,* pp. 159-172.

BALMANN, A., HAPPE, K., KELLERMANN, K., KLEINGARN, A. (2002): Adjustment Costs of Agri-Environmental Policy Switchings: An Agent-Based Analysis of the German Region Hohenlohe, in: JANSSEN, M. A. (ed.): Complexity and ecosystem management – The theory and practice of multi-agent systems, Edward Elgar, Cheltenham, Northhampton, pp. 127-157.

BANKES, S. (1993): Exploratory Modelling for Policy Analysis, *Operations Research*, *41(3),* pp. 435-449.

BERG, E. (1980): Ein Simulationsmodell zur Darstellung der Arbeitskräfte- und Flächenmobilität in der Landwirtschaft, Habilitationsschrift, Bonn.

BERGER, T. (2004): Agentenbasierte Modellierung von Landnutzungsdynamiken und Politikoptionen, *Agrarwirtschaft*, *53(2),* pp. 77-87.

BERGER, T., BRANDES, W. (1998): Evolutionäre Ansätze in der Agrarökonomik, *Agrarwirtschaft*, *47(4),* pp. 275-282.

BOOCH, G., RUMBAUGH, J., JACOBSON, I. (1999): The Unified Modeling Language User Guide, *Object Technology Series,* Addison-Wesley, Redwood City.

BRANDES, W. (1978): Zur Konzentration der Agrarproduktion in der Bundesrepublik Deutschland aus betriebswirtschaftlicher Sicht, *Agrarwirtschaft*, *27(1),* pp. 1-12.

BRANDES, W. (1985): Über die Grenzen der Schreibtischökonomie, Tübingen.

BRANDES, W. (1995): Pfadabhängigkeit: Ein auch für die Agrarökonomik fruchtbares Forschungsprogramm?, *Agrarwirtschaft*, *44(8/9),* pp. 277-279.

DAVID, P. A. (1985): Clio and the Economics of QWERTY, *American Economic Review*, *Proceedings 75,* pp. 332-337.

DAY, R. H. (1963): Recursive Programming and Production Response, North-Holland, Amsterdam.

DE HAEN, H. (1971): Dynamisches Regionalmodell der Produktion und Investition in der Landwirtschaft, *Agrarwirtschaft, Sonderheft 43,* Alfred Strothe, Hannover.

DOSI, G. (1997): Opportunities, Incentives and the Collective Patterns of Technological Change, *The Economic Journal*, *107,* pp. 1530-1547.

FAPRI – Food and Agricultural Policy Research Institute (2003): FAPRI 2003 – U.S. and World Agricultural Outlook, *Staff Report 1-03,* Food and Agricultural Policy Research Institute Iowa State University, University of Missouri Columbia.

FERBER, J. (1999): Multi-Agent Systems: An Introduction to Distributed Artificial Intelligence, Addison-Wesley.

FINKENSTÄDT, B. (1995): Nonlinear dynamics in economics: A theoretical and statistical approach to agricultural markets, *Lecture Notes in Economics and Mathematical Systems, 426,* Berlin.

FRANKLIN, S., GRAESSER, A. (1997): Is it an Agent, or just a Program? A taxonomy for Autonomous Agents, in: MÜLLER, J. P., WOOLDRIDGE, M. J., JENNINGS, J. P. (eds.): Intelligent Agents III: Agent Theories, Architectures, and Languages, *Lecture Notes in Artificial Intelligence 1193,* Springer, Berlin, Heidelberg, pp. 21-35.

GILBERT, N., TROITZSCH, K. (1999): Simulation for the Social Scientist, Open University Press, Buckingham.

GUYOMARD, H., BAUDRY, M., CARPENTIER, A. (1996): Estimating Crop Supply Response in the Presence of Farm Programmes: Application to the CAP, *European Review of Agricultural Economics*, *23,* pp. 401-420.

HANF, C.-H. (1989): Agricultural sector analysis by linear programming models – Approaches, problems and experiences, Wissenschaftsverlag Vauk, Kiel.

HANNEMAN, R., PATRICK, S. (1997): On the Uses of Computer-Assisted Simulation Modeling in the Social Sciences, *Sociological Research Online, 2(2),* <http://www.socresonline.org.uk/socresonline/2/2/5.html>.

HAPPE, K., BALMANN, A. (2002): Struktur-, Effizienz- und Einkommenswirkungen von Direktzahlungen, *Agrarwirtschaft*, *51(8),* pp. 376-388.

HAPPE, K., BALMANN, A. (2003): The effect of direct payments on structure, efficiency, and farm incomes, CD "Proceedings of the 25th International Conference of Agricultural Economists (IAAE) 'Reshaping Agriculture's Contributions to Society'", Durban/South Africa, 16.-22.08.2003.

HAZELL, P. B. R., NORTON, R. D. (1986): Mathematical Programming for Economic Analysis in Agriculture, Macmillan, New York.

HECKELEI, T., WITZKE, H. P., HENRICHSMEYER, W. (eds.) (2001): Agricultural Sector Modelling and Policy Information Systems, Proceedings of the 65th European Seminar of the European Association of Agricultural Economists, Wissenschaftsverlag Vauk, Kiel.

HEIDHUES, T. (1966): Entwicklungsmöglichkeiten landwirtschaftlicher Betriebe unter verschiedenen Preisannahmen, Paul Parey, Hamburg.

HERTEL, T. W. (ed.) (1997): Global Trade Analysis: Modeling and Applications, Cambridge University Press, Cambridge.

JACOBS, A. (1998): Paralleler Einsatz von Regionen- und Betriebsgruppenmodellen in der Agrarsektoranalyse, in: BUNDESMINISTERIUMS FÜR ERNÄHRUNG, LANDWIRTSCHAFT UND FORSTEN (Hrsg.): Schriftenreihe *Angewandte Wissenschaft, H. 470.*

JENNINGS, N. R., SYCARA, K., WOOLDRIDGE, M. (1998): A roadmap of agent research and development, *Autonomous Agents and Multi-Agent Systems, 1*, pp. 7-38.

KAZENWADEL, G. (1999): Ökonomisch/ökologische Beurteilung von regionalen Agrar- und Umweltprogrammen in der Europäischen Union, *Agrarwirtschaft, Sonderheft 162,* Bergen/Dumme.

KELLERMANN, K. (2002): PlayAgriPoliS – Ein agentenbasiertes Politikplanspiel, Diplomarbeit, Humboldt Universität zu Berlin, mimeo.

KUHLMANN, F., BERG, E. (2002): The Farm as an Enterprise – The European Perspective, 13th International Congress of Farm Management, Papendal Conference Center, Arnhem/The Netherlands, 07.-12. July 2002.

KUHN, A. (2003): From World Market to Trade Flow Modelling – The Re-Designed WATSIM Model, Final Report on the Project: WATSIM AMPS, Research Report, Institute of Agricultural Policy, Market Research and Economic Sociology, University of Bonn.

LENTZ, W. (1993): Neuere Entwicklungen in der Theorie dynamischer Systeme und ihre Bedeutung für die Agrarökonomie, Duncker & Humblot, Berlin.

LUCK, M., MCBURNEY, P., PREIST, C. GUILFOYLE, C. (2003): Agent Technology: Enabling Next Generation Computing – A Roadmap for Agent Based Computing, AgentLink II, retrieved from internet: <*www.agentlink.org*>, November 2003.

MANSON, S. M. (2002): Validation and verification of multi-agent systems, in: JANSSEN, M. A. (ed.): Complexity and ecosystem management – The theory and practice of multi-agent systems, Edward Elgar, Cheltenham, Northhampton, pp. 63-74.

MÜLLER, H.-U. (2002): Strategien zur Verminderung von Gasemissionen aus der Milchviehhaltung in einer intensiven Grünlandregion, Shaker-Verlag, Aachen.

MÜNCH, W. (2002): *Effects of CEC-EU Accession on Agricultural Markets: A Partial Equilibrium Analysis,* Verlag Peter Lang, Frankfurt a. Main.

NUTHALL, P. L. (2001): Managerial ability – A review of its basis and potential improvement using psychological concepts, *Agricultural Economics, 24,* pp. 247-262.

OUDE LANSINK, A., PEERLINGS, J. (1996): Modelling the New EU Cereals Regime in the Netherlands, *European Review of Agricultural Economics, 23,* pp. 161-178.

OUDE LANSINK, A., PIETOLA, K., BÄCKMAN, S. (2002): Efficiency and productivity of conventional and organic farms in Finland 1994-1997, *European Review of Agricultural Economics*, *29(1)*, pp. 51-65.

PARKER, D. C., BERGER, T., MANSON, S. M., MCCONNELL, W. J. (eds.) (2002): Agent-Based Models of Land-Use/Land-Cover Change, Report and Review of an International Workshop October 4-7, 2001, Irvine, California/USA, *LUCC Report Series No. 6.*

REISS, S. P. (1999): A Practical Introduction to Software Design with C++. John Wiley & Sons, New York.

RONINGEN, V., SULLIVAN, F., DIXIT, P. (1991): Documentation of the Static World Policy Simulation (SWOPSIM) Modeling Framework. U.S. Department of Agriculture, *ERS Staff Report No. AGES 9215,* Washington D.C.

ROUGOOR, C. W., TRIP, G., HUIRNE, R. B. M., RENKEMA, J. A. (1998): How to define and study farmers' management capacity: Theory and use in agricultural economics, *Agricultural Economics, 18,* pp. 261-272.

RUSSEL, S., NORVIG, P. (1995): Artificial Intelligence: A Modern Approach, Englewood Cliffs, NJ.

SALVATICI, L., ANANIA, G., ARFINI, F., CONFORTI, P., MURO, P. D., PONDERO, P., SCKOKAI, P. (2001): Recent developments in modelling the CAP: Hype or hope?, in: HECKELEI, T., WITZKE, H. P., HENRICHSMEYER, W. (eds.): Agricultural Sector Modelling and Policy Informations Systems, Wissenschaftsverlag Vauk, Kiel, pp. 8-26.

SCHLEEF, K.-H. (1999): Auswirkungen von Stickstoffminderungspolitiken – Modellgestützte Abschätzung der betrieblichen Auswirkungen von Politiken zur Verringerung von Stickstoffüberschüssen aus der Landwirtschaft, in: BUNDESMINISTERIUMS FÜR ERNÄHRUNG, LANDWIRTSCHAFT UND FORSTEN (Hrsg.): Schriftenreihe *Angewandte Wissenschaft, H. 482.*

STOKER, T. M. (1993): Empirical approaches to the problem of aggregation over individuals, *Journal of Economic Literature, 31(4),* pp. 1827-1875.

WOSSINK, A. (1993): Analysis of future agricultural change – A farm economics approach applied to Dutch arable farming, PhD-Thesis, Wageningen University.

APPENDIX

Tabelle A-1: Data output at farm and sector level (selection)

Farm level	Unit	Sector level	Unit
Structure		Production	
Farm size	ha	Region totals	ha, LU
Economic size	ESU	Inputs	
Farm type		Total land input	ha
Main income source	Part-time/ full-time	Total capital input	€
Owned land	ha	Total labour	h
Rented land	ha	Investment	
Production		Investment expenditure	€
Output in quantities	ha, LU		
Output in value	€	Sector totals of farm level data	various units
Costs			
Overheads	€	**Farm level**	**Unit**
Maintenance	€	Financial situation	
Depreciation	€	Profit	€
Wages paid	€	Equity capital	€
Rent paid	€	Change in equity	€
Interest paid	€	Net investments	€
Annualised average costs of fixed capital	€	Income and labour	
Variable costs	€/unit	Labour input	h
Subsidies		Family labour	h
Direct payments	€	Farm net value added	€
Land		Total household income	€
Economic land rent	€/ha	Off-farm income	€
Rent paid arable land	€/ha		
Rent paid grassland	€/ha		
Balance sheet			
Total assets	€		
Total fixed assets	€		
Total land assets	€		
Liquidity	€		
Borrowed capital	€		
Short-term borrowed capital	€		

**DISCUSSION PAPERS
DES INSTITUTS FÜR AGRARENTWICKLUNG
IN MITTEL- UND OSTEUROPA (IAMO)**

**DISCUSSION PAPERS
OF THE INSTITUTE OF AGRICULTURAL DEVELOPMENT
IN CENTRAL AND EASTERN EUROPE (IAMO)**

No. 1 FROHBERG, K., HARTMANN, M. (1997):
Promoting CEA Agricultural Exports through Association Agreements with the EU – Why is it not working?

No. 2 FROHBERG, K., HARTMANN, M. (1997):
Comparing Measures of Competitiveness: Examples for Agriculture in the Central European Associates

No. 3 POGANIETZ, W. R., GLAUCH, L. (1997):
Migration durch EU-Integration? Folgen für den ländlichen Raum

No. 4 WEINGARTEN, P. (1997):
Agri-Environmental Policy in Germany – Soil and Water Conversation –

No. 5 KOPSIDIS, M. (1997):
Marktintegration und landwirtschaftliche Entwicklung: Lehren aus der Wirtschaftsgeschichte und Entwicklungsökonomie für den russischen Getreidemarkt im Transformationsprozeß

No. 6 PIENIADZ, A. (1997):
Der Transformationsprozeß in der polnischen Ernährungsindustrie von 1989 bis 1995

No. 7 POGANIETZ, W. R. (1997):
Vermindern Transferzahlungen den Konflikt zwischen Gewinnern und Verlierern in einer sich transformierenden Volkswirtschaft?

No. 8 EPSTEIN, D. B., SIEMER, J. (1998):
Difficulties in the Privatization and Reorganization of the Agricultural Enterprises in Russia

No. 9 GIRGZDIENE, V., HARTMANN, M., KUODYS, A., RUDOLPH, D., VAIKUTIS, V., WANDEL, J. (1998):
Restructuring the Lithuanian Food Industry: Problems and Perspectives

No. 10 JASJKO, D., HARTMANN, M., KOPSIDIS, M., MIGLAVS, A., WANDEL, J. (1998):
Restructuring the Latvian Food Industry: Problems and Perspectives

No. 11 SCHULZE, E., NETZBAND, C. (1998):
Ergebnisse eines Vergleichs von Rechtsformen landwirtschaftlicher Unternehmen in Mittel- und Osteuropa

No. 12 BERGSCHMIDT, A., HARTMANN, M. (1998):
Agricultural Trade Policies and Trade Relations in Transition Economies

No. 13 ELSNER, K., HARTMANN, M. (1998):
Convergence of Food Consumption Patterns between Eastern and Western Europe

No. 14 FOCK, A., VON LEDEBUR, O. (1998):
Struktur und Potentiale des Agraraußenhandels Mittel- und Osteuropas

No. 15 ADLER, J. (1998):
Analyse der ökonomischen Situation von Milchproduktionsunternehmen im Oblast Burgas, Bulgarien

No. 16 PIENIADZ, A., RUDOLPH, D. W., WANDEL, J. (1998):
Analyse der Wettbewerbsprozesse in der polnischen Fleischindustrie seit Transformationsbeginn

No. 17 SHVYTOV, I. (1998):
Agriculturally Induced Environmental Problems in Russia

No. 18 SCHULZE, E., TILLACK, P., DOLUD, O., BUKIN, S. (1999):
Eigentumsverhältnisse landwirtschaftlicher Betriebe und Unternehmen in Rußland und in der Ukraine – Befragungsergebnisse aus den Regionen Nowosibirsk und Shitomir

No. 19 PANAYOTOVA, M., ADLER, J. (1999):
Development and Future Perspectives for Bulgarian Raw Milk Production towards EU Quality Standards

No. 20 WILDERMUTH, A. (1999):
What Kind of Crop Insurance for Russia?

No. 21 GIRGZDIENE, V., HARTMANN, M., KUODYS, A., VAIKUTIS, V., WANDEL, J. (1999):
Industrial Organisation of the Food Industry in Lithuania: Results of an Expert Survey in the Dairy and Sugar Branch

No. 22 JASJKO, D., HARTMANN, M., MIGLAVS, A., WANDEL, J. (1999):
Industrial Organisation of the Food Industry in Latvia: Results of an Expert Survey in the Dairy and Milling Branches

No. 23 ELSNER, K. (1999):
Analysing Russian Food Expenditure Using Micro-Data

No. 24 PETRICK, M., DITGES, C. M. (2000):
Risk in Agriculture as Impediment to Rural Lending – The Case of North-western Kazakhstan

No. 25 POGANIETZ, W. R. (2000):
Russian Agri-Food Sector: 16 Months After the Breakdown of the Monetary System

No. 26 WEBER, G., WAHL, O., MEINLSCHMIDT, E. (2000):
Auswirkungen einer EU-Osterweiterung im Bereich der Agrarpolitik auf den EU-Haushalt
(steht nicht mehr zur Verfügung – aktualisierte Version DP 42)

No. 27 WAHL, O., WEBER, G., FROHBERG, K. (2000):
Documentation of the Central and Eastern European Countries Agricultural Simulation Model (CEEC-ASIM Version 1.0)

No. 28 PETRICK, M. (2000):
Land Reform in Moldova: How Viable are Emerging Peasant Farms? An assessment referring to a recent World Bank study

No. 29 WEINGARTEN, P. (2000):
Buchbesprechung: BECKMANN, V. (2000): Transaktionskosten und institutionelle Wahl in der Landwirtschaft: Zwischen Markt, Hierarchie und Kooperation

No. 30 BROSIG, S. (2000):
A Model of Household Type Specific Food Demand Behaviour in Hungary

No. 31 UVAROVSKY, V., VOIGT, P. (2000):
Russia's Agriculture: Eight Years in Transition – Convergence or Divergence of Regional Efficiency

No. 32 SCHULZE, E., TILLACK, P., GERASIN, S. (2001):
Eigentumsverhältnisse, Rentabilität und Schulden landwirtschaftlicher Großbetriebe im Gebiet Wolgograd

No. 33 KIELYTE, J. (2001):
Strukturwandel im baltischen Lebensmittelhandel

No. 34 ШУЛЬЦЕ, Э., ТИЛЛАК, П., ГЕРАСИН, С. (2001):
Отношения собственности, рентабельность и долги крупных сельскохозяйственных предприятий в Волгоградской области

No. 36 PETRICK, M. (2001):
Documentation of the Poland farm survey 2000

No. 37 PETRICK, M., SPYCHALSKI, G., ŚWITŁYK, M., TYRAN, E. (2001):
Poland's Agriculture: Serious Competitor or Europe's Poorhouse? Survey results on farm performance in selected Polish voivodships and a comparison with German farms

No. 38 HOCKMANN, H., KASHTANOVA, E., KOWSCHIK, S. (2002):
Lage und Entwicklungsprobleme der weißrussischen Fleischwirtschaft

No. 39 SCHULZE, E., TILLACK, P., PATLASSOV, O. (2002):
Einflussfaktoren auf Gewinn und Rentabilität landwirtschaftlicher Großbetriebe im Gebiet Omsk, Russland

No. 40 ШУЛЬЦЕ, Э., ТИЛЛАК, П., ПАТЛАССОВ, О. (2002):
Факторы, влияющие на прибыль и рентабельность крупных сельскохозяйственных предприятий в Омской области в России

No. 41 BAVOROVÁ, M. (2002):
Entwicklung des tschechischen Zuckersektors seit 1989

No. 42 FROHBERG, K., WEBER, G. (2002):
Auswirkungen der EU-Osterweiterung im Agrarbereich

No. 43 PETRICK, M. (2002):
Farm investment, credit rationing, and public credit policy in Poland
– A microeconometric analysis –

No. 44 KEDAITIENE, A., HOCKMANN, H. (2002):
Milk and milk processing industry in Lithuania: An analysis of horizontal and vertical integration

No. 45 PETRICK, M. (2003):
Empirical measurement of credit rationing in agriculture: A methodological survey

No. 46 PETRICK, M., LATRUFFE, L. (2003):
Credit access and borrowing costs in Poland's agricultural credit market: A hedonic pricing approach

No. 47 PETRICK, M., BALMANN, A., LISSITSA, A. (2003):
Beiträge des Doktorandenworkshops zur Agrarentwicklung in Mittel- und Osteuropa 2003

No. 48 SCHULZE, E., TILLACK, P., MOSASHWILI, N. (2003):
Zur wirtschaftlichen Situation georgischer Landwirtschaftsbetriebe

No. 49 ЛИССИТСА, А., БАБИЧЕВА, Т. (2003):
Теоретические основы анализа продуктивности и эффективности сельскохозяйственных предприятий

No. 50 ЛИССИТСА, А., БАБИЧЕВА, Т. (2003):
Анализ Оболочки Данных (DEA) – Современная методика определения эффективности производства

No. 51 ЛИССИТСА, А., ОДЕНИНГ, М., БАБИЧЕВА, Т. (2003):
10 лет экономических преобразований в сельском хозяйстве Украины – Анализ эффективности и продуктивности предприятий

No. 52 STANGE, H., LISSITSA, A. (2003):
Russischer Agrarsektor im Aufschwung? Eine Analyse der technischen und Skaleneffizienz der Agrarunternehmen

No. 53 VALENTINOV, V. (2003):
Social capital, transition in agriculture, and economic organisation: A theoretical perspective

No. 54 BORKOWSKI, A. (2003):
Machtverteilung im Ministerrat nach dem Vertrag von Nizza und den Konventsvorschlägen in einer erweiterten Europäischen Union

No. 55 KISS, P., WEINGARTEN, P. (2003):
Cost of compliance with the acquis communautaire in the Hungarian dairy sector

No. 56 WEINGARTEN, P., FROHBERG, K., WINTER, E., SCHREIBER, C. (2003):
Quantitative Analysis of the Impacts of Croatia's Agricultural Trade Policy on the Agri-food Sector

No. 57 БОКУШЕВА, Р., ХАЙДЕЛЬБАХ, О. (2004):
Актуальные аспекты страхования в сельском хозяйстве

No. 58 DERLITZKI, R., SCHULZE, E. (2004):
Georg Max Ludwig Derlitzki (1889-1958)

No. 59 VŐNEKI, E. (2004):
Zur Bewertung des Ungarischen SAPARD-Programms unter besonderer Berücksichtigung der Investitionen im Milchsektor

No. 60 ЧИМПОЕШ, Д., ШУЛЬЦЕ, Э. (2004):
Основные экономические проблемы сельского хозяйства Молдовы

No. 61 BAUM, S, WEINGARTEN, P. (2004):
Interregionale Disparitäten und Entwicklung ländlicher Räume als regionalpolitische Herausforderung für die neuen EU-Mitgliedstaaten

No. 62 PETRICK, M. (2004):
Can econometric analysis make (agricultural) economics a hard science? Critical remarks and implications for economic methodology

No. 63 SAUER, J. (2004):
Rural Water Suppliers and Efficiency – Empirical Evidence from East and West Germany

No. 64 PETRICK, M., BALMANN, A. (2004):
Beiträge des 2. Doktorandenworkshops zur Agrarentwicklung in Mittel- und Osteuropa 2004

No. 65 BOJNEC, S., HARTMANN, M. (2004):
Agricultural and Food Trade in Central and Eastern Europe: The Case of Slovenian Intra-Industry Trade

No. 66 GLITSCH, K, EERITS, A. (2004):
Der slowakische Markt für Milch und Milchprodukte – Von Beginn der Transformation bis zum EU-Beitritt

No. 67 FISCHER, C. (2004):
Assessing Kosovo's horticultural potential – The market for fruit and vegetables on the balkans

No. 68 PETRICK, M., SCHREIBER, C., WEINGARTEN, P. (2004):
Competitiveness of milk and wine production and processing in Albania

No. 69 ШТАНГЕ, Г., ЛИССИТСА, А. (2004):
Аграрный сектор России на подъеме?! Анализ технической эффективности аграрных предприятий

No. 70 SAUER, J. (2004):
Die Ökonomie der (Ländlichen) Wasserversorgung

No. 71 HAPPE, K., BALMANN, A., KELLERMANN, K. (2004):
The Agricultural Policy Simulator (Agripolis) – An agent-based model to study structural change in agriculture (Version 1.0)

Die Discussion Papers sind erhältlich beim Institut für Agrarentwicklung in Mittel- und Osteuropa (IAMO) oder im Internet unter http://www.iamo.de.

The Discussion Papers can be ordered from the Institute of Agricultural Development in Central and Eastern Europe (IAMO). Use our download facility at http://www.iamo.de.