The Use of Agent-Based Modelling to Establish a Link between Agricultural Policy Reform and Structural Change

Kathrin Happe[1], Alfons Balmann[1], Konrad Kellermann[1], Christoph Sahrbacher[1]

[1] Institute of Agricultural Development in Central and Eastern Europe (IAMO)

Contribution appeared in Arfini, F. (Ed.) (2005) "Modelling Agricultural Policies: State of the Art and New Challenges", proceedings of the 89th EAAE Seminar, pp. 138 - 164

February 2-5, 2005

Parma, Italy

The Use of Agent-Based Modelling to Establish a Link between Agricultural Policy Reform and Structural Change

Kathrin Happe, Alfons Balmann, Konrad Kellermann, Christoph Sahrbacher

Institute of Agricultural Development in Central and Eastern Europe (IAMO)*

Abstract

This paper motivates the use of agent-based modelling to study policy impacts on systems of heterogeneous, individually acting agents, such as agricultural structures. The paper presents the model AgriPoliS and an application to a region in southwest Germany. The policies considered in the simulation experiments aim at increasing the efficient allocation of production factors. Results show that policies providing incentives for small farms to leave the sector speed up structural change and increase efficiency. The paper ends with an extensive discussion of model results, and the approach.

Key words: policy analysis, simulation, agent-based modelling, structural change, efficiency.

1. Introduction

1.2 The role of agricultural policies in structural adjustment

Agricultural structures have been shaped by a variety of factors including economic, cultural, historical, political, technological, and geographical conditions. Hence, agricultural structures are not static but change. Structural change can be viewed as an evolutionary process, which is an integral part of any economy. It can be characterised – amongst other things – by a constant adjustment to changes in demand, supply, and technological progress (OECD 1994). This process is ideally guided by market signals, which convey information about social preferences and production possibilities. The degree to which agricultural structures can adjust to market signals depends on the extent to which production factors can move to areas where their pro-

* Theodor-Lieser-Str. 2, 06114 Halle (Saale), Germany.

ductivity is highest. In this sense, the mobility of production factors is central to the competitiveness and efficiency of agriculture.

Market activity, however, also takes place within a policy framework. Policies set the rules for market activity, but they can directly interfere with the adjustment processes on markets, too. Regarding the latter, the role of agricultural policies is twofold. On the one hand, policies can alter the capacity of the agricultural sector – and thus of agricultural structures – to adjust and create incentives for adjustments. On the other hand, policies can also impede structural adjustment, for example, by (artificially) increasing the profitability of one production activity relative to others. This affects the allocation of the production factors land, labour, and capital and thus creates market distortions, which are considered inefficient. Thus, interference of policies with the adjustment process is likely to create both costs and benefits in an economy (Goddard et al., 1993).

The development of competitive and efficient agricultural structures has been one of the central goals of agricultural policy making in addition to ensuring a fair standard of living for farmers. To achieve these goals, the agricultural sector in most industrialised nations has long been the subject of government interventions. However, many agricultural policies have worked counteractively to these goals by creating distortions in the use and mobility of production factors (e.g. Dewbre et al., 2001; OECD, 1995, 1994; Fennell, 1999; Balmann, 1995). In principle, policies contributed to inhibit those structural adjustment processes, which would take place without support. Distortions emerge mainly because policies providing support to farming activity are considered to attract additional resources (in particular labour and capital) to farming activities than would be the case without support (OECD 1994). The result is that agricultural support policies may impede structural adjustment by providing incentive for marginal farms to remain in the sector and thus retard the development towards more efficient agricultural structures.

Stimulated by the above considerations, throughout the past half century, agricultural economists have argued repeatedly that agricultural policies could actually be defined and implemented in a way that lifts many impediments to the policy and promotes efficiency and competitiveness (e.g. Koester and Tangermann, 1976; Fennell, 1997; Swinbank and Tangermann, 2000; Baffes, 2004; Beard and Swibank, 2001). The key reform principle behind these proposals has been to reduce market protection and to facilitate responsiveness to market conditions by agricultural producers through policy measures that result in lower support delivered in less distorting ways. In this way, a policy reform should be expected to positively influence the efficiency and competitiveness of agricultural structures.

Several policies have been envisaged to achieve these goals: besides successive cuts in market support prices, policies going in this vein could be direct payments which are fully decoupled from production, a successive reduction of any kind of support, as well as incentive payments to remove surplus labour of all ages from farming. What all of these policies have in common is that they exert adjustment pressure on existing producers and hence are expected to increase structural adjustment processes towards a more efficient allocation of factors. The actual nature of structural adjustment due to policy reform would depend on the pace and scope of the reform, structural and natural characteristics of affected regions, and in particular, on individual farmers' capacity to adjust.

The latter point requires special attention as it indicates that individual behaviour, local conditions, and thus, interactions and heterogeneity gain importance when studying the adjustment reactions to agricultural policy change. In other words, what matters are the specific conditions of individual farms. The degree to which individual farms can adjust is determined by a number of factors, such as a farm's technology, managerial ability, size, location, specialisation, factor endoment, opportunity costs of (human and asset) capital, etc. Depending on these fators, possible adjustment reactions may be manifold ranging from a change of the product mix, investment, or disinvestment, to changing the income mix between on and off-farm income sources. Moreover, farms may also entirely withdraw from the sector. However, on the side of the farms, there may also be some factors that hinder adjustment such as low opportunity costs of production factors. Hence, sunk costs lead to the effect that farms may continue production although their long run opportunity costs are not covered (Balmann et al., 1996).

1.2 Consequences for modelling

Thus, when studying farms' and the agricultural sector's adjustment reactions in response to a policy change and its dynamics, the question arises, how well agricultural economics is equipped with tools to accompany such policy reforms with quantitative analyses that explicitly take individual farms' adjustment processes as well as structural developments over time into account? From a modelling point of view, it is thus important to find appropriate ways of modelling adjustment reations to policy change. Against this background, the emergence of new and innovative modelling methods such as agent-based modelling, in addition to ever-increasing computing capacities has offered new possibilities to model adjustment reactions and to quantify the impact of agricultural policies on a range of indicators.

1.3 Objectives and structure of the paper

This paper takes up the comparatively new methodology of agent-based modelling and applies it to a concrete problem to gain more insight into the impact of agricultural policy measures on regional structural change. More specifically, in this study we apply the agent-based model AgriPoliS (Agricultural Policy Simulator) to a selected region, which is the family-farm dominated region 'Hohenlohe' in southwest Germany. The aim of this paper is to simulate and analyse the effects of three different policy reforms aimed at reducing impediments to structural adjustment while, at the same time, increasing the efficient allocation of production factors. Even if, in reality, a bundle of (often complementary) policies affects structural change, the simulation experiments in this paper consider one policy at a time. The aim is to identify the

specific adjustment patterns induced by the respective policy measure. The emphasis is on support given by way of direct payments.
The starting point of the analysis is the hypothesis that Hohenlohe's agricultural structure displays structural inefficiencies because structural adjustment in the past has been impeded by existing agricultural policies and factor immobilities. Moreover, in this study, it is assumed that the impeding impact of policies has been aggravated in some regions by existing structural deficits, which can be attributed mainly to three phenomena. First, unexploited returns to scale leading to an inefficient use of production factors; second, adjustment costs were causing the immobility of production factors, and third, path dependencies meaning that a path, e.g., a specialisation or the emergence of a specific structure once taken, can only be left at high costs.
The structure of the paper as follows: Section 2 presents the agent-based, spatial and dynamic model AgriPoliS. The model draws upon previous work by Balmann (1995, 1997) and extends the model in several directions. The particular feature of AgriPoliS is that it establishes a virtual model world on the computer, the rules of which can be fully controlled by the modeller. It allows modelling a large number of individually acting farms operating in a region as well as farms' interactions with each other and with parts of their environment. Simulation experiments with AgriPoliS generate an extensive dataset of indicators for individual farms and the entire region based on which a host of questions can be analysed using different analysis techniques. Section 3 briefly presents how the case study region Hohenlohe is represented in AgriPoliS. The policies considered in the simulation experiments are presented in Section 4 before selected simulation results are presented in Section 5. The paper ends with a critical discussion of the results and the used methodology.

2. The agent-based model AgriPoliS

This study uses the simulation model AgriPoliS (Agricultural Policy Simulator) (Happe et al. 2004) to generate a comprehensive simulated dataset on many individual farms under different policy conditions. AgriPoliS is a further development of a model originally developed by Balmann (1997) to study path dependencies in structural change. AgriPoliS aims to map the key structural components of an agricultural system and simulate changes in the composition of the agricultural structure. In brief, an agricultural system can be described as consisting of the three key factors heterogeneous farms, land, markets for production factors and products. These are embedded in the technological and political environment.

The core of AgriPoliS is the understanding and modelling of the agricultural system as an agent-based system (Happe, 2004; Balmann and Happe, 2001) in which farms are interpreted as individual agents. Agents are situated in environments in which they interact, co-operate, and exchange information with other agents that have possibly conflicting aims. Such environments are known as agent-based systems (ABS). 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; Jennings et al., 1998; Luck et al., 2003; Russel and Norvig, 1995). In the context of regional agricultural structures, it is useful to differentiate between two kinds of agents: the farm agent and the market agent[1]. The agents in AgriPoliS are acting entities that carry out defined actions.

Farm agents in AgriPoliS are founded in neo-classical production theory and farm agents aim to maximise household income. In fact, AgriPoliS combines methods, techniques, and assumptions which have been around farm in management and farm planning for many decades and which are well known. The most important of these techniques is linear programming (in this case extended to mixed-integer programme). AgriPoliS, however, may be specific and new with regard to at least three aspects. First, it brings together these well-known techniques in a single model. Second, farm agents in AgriPoliS are heterogeneous with regard to factor endowments, location, farm type, and managerial ability of the farmer, just as real farms. Because of this, the starting conditions of farms when competing on markets differ and some farms maybe more suited to react adequately to changes in the prices and policies than others. And finally, AgriPoliS considers interactions between farm agents in the form of factor and product markets on which prices are determined endogenously. The following provides a brief overview of AgriPoliS. The model is documented in detail in Happe et al. (2004.)

2.1 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 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 1).

[1] 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.

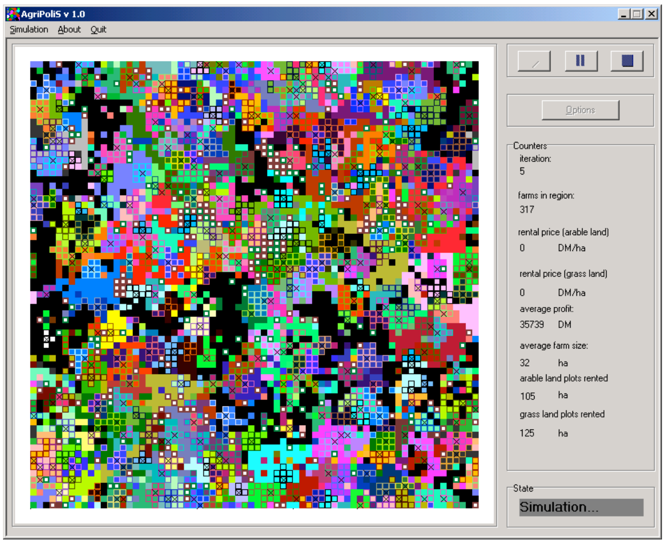

Figure 1. An idealised grid representation of an agricultural region in AgriPoliS

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.

2.2 Agents involved

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.

2.3 The Farm agent

2.3.1 Behavioural foundation

Farm agents are assumed to be autonomously acting units following a given behaviour which is assumed to remain constant throughout a simulation. Farm agents can produce a selection of goods. In order to produce, farm agents utilise buildings, machinery, and facilities of different types and capacities. 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[2]. 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 such as labour, manure export and import, and quota lease are 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.

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

[2] 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.

limit on livestock density, or the nutrient balance. In more formal terms the mixed-integer optimisation problem is expressed as

$$\max Y^e(\mathbf{x},\mathbf{p^e},\mathbf{c},\mathbf{A},\mathbf{I},\mathbf{r},MP,D,RE,L,BC,IC,GL,AL,\ldots)$$

$$\text{with} \qquad Y^e = \mathbf{x}'(\mathbf{p^e}-\mathbf{c}) + IR + S + W - RE - MC - D - OV - TC - IC - HW\,. \qquad (1)$$

$$\text{s.t.} \quad \mathbf{b} \geq \mathbf{x}'\mathbf{R} \qquad \text{with} \quad \mathbf{R} = (r_1,\ldots,r_I,\ldots,r_H,\ldots,r_J)$$

$$\mathbf{x} \geq 0$$

This optimisation problem produces shadow prices for scarce resources. Particularly the shadow price of land is of interest because it provides the basis for the production of bids in the land auction.

2.3.2 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[3]. By doing so, dynamic effects resulting from expectations about the development of markets and demand developments are neglected. Farm agents also follow the same pattern of expectation formation, i.e. there is no differentiation between optimists and pessimists.

Regarding prices, farm agents follow adaptive expectations defined in terms of the weighted geometric average of actual and expected prices[4]. 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.

A farm agent also forms expectations about the costs of carrying out production activities. Here it is necessary to distinguish between the direct costs of carrying out livestock or plant 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 of livestock production activity produced with a certain investment object decline by a factor representing the impact of technological change.

[3] 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.

[4] 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[5].

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 at the end of a planning period. 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.

2.3.3 Production

Each farm agent is assumed to optimise production in any one planning period subject to available production capacities using the planning approach described 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.

2.3.4 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. Farm agents can choose from a range of investment options of different types, capacities and sizes. The latter allows implementing size effects, i.e. with increasing size, the costs per unit of production capacity decrease and labour is assumed to be used more effectively. Farm agents make investment decisions based on the average annual costs of an investment. 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.

2.3.5 Renting land

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

[5] 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.

economies of size for machinery 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, for a plot of grassland or arable land is a combination of the plot's shadow price, transport costs between the farmstead and the plot, the number of adjacent plots, and a parameter representing the proportion of the shadow price of an additional plot remaining with the farm agent.

2.3.6 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, based on which a decision on whether or not to continue farming is made. One reason for a farm agent to withdraw from farming is related to negative equity. 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 a given amount per year.

Lasting farm profitability, and therefore a farm agent's probability to remain in farming, 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. As costs of fixed assets are assumed to be sunk, they are not considered in this calculation. Consequently, a second reason for a farm agent to stop farming would be given if profit does not cover opportunity costs of farm-owned production factors, taking account of price, cost and policy changes for the next period.

2.3.7 Other factors

Besides renting land, farm agents 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. This offers the possibility for non-professional farming, on the one hand, and reducing the overall farm labour if necessary on the other. 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.

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.

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 nontradable. 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.

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 because differences in the economic performance of farmers are often attributed to differences in the managerial ability of farmers (Nuthall, 2001; Rougoor et al., 1998). Accordingly, production costs are lower if managerial ability is higher. In the current version of AgriPoliS, farm agents cannot learn and improve managerial ability.

2.4 The market agents

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). Either interactions between agents take place 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.

2.4.1 The land market auctioneer

In AgriPoliS, the land market is the central interaction institution between agents, governed by a land auctioneer. AgriPoliS exclusively considers a land rental market. 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. 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.

2.4.2 The product market agent

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 the price is a function of the price in the first period of the simulation adjusted by time trend and the total quantity of a product traded.

3. Model calibration and empirical data base[6]

To calibrate AgriPoliS to the Hohenlohe region we represent the agricultural structure in the reference year 2000/2001 based on typical farms, i.e., farms one could typically find in the region. Sahrbacher (2003) developed a procedure, based on Balmann et al. (1998), to simultaneously select typical farms and scale them up to represent a range of regional capacities. The approach identifies typical farms of different types and sizes, on the one hand. On the other, it generates a scaling factor for each typical farm selected. This factor denotes the number of times a typical farm has to be located in the region such that the agricultural structure of the region is represented best.

This particular approach requires two kinds of data: first, data about the region representing aggregate regional capacities, and, second, data about farm organisation as well as economic indicators of individual farms in the region from which to select typical farms. Regarding the first requirement, regional statistical data sources were available, e.g. from the Statistical Office of Baden-Württemberg. As for individual farm data, farm accountancy data (as collected in the German farm accountancy data network) compiling information about farm organisation and economic indicators, provided a suitable data source. Although farms in the farm accountancy data sample are not representative, the sample nevertheless covers the most important farm types in the region. For Hohenlohe, farm accountancy data from 101 full-time and 20 part-time farms were available in the reference year 2000/2001. Considering that about 50% of all farms in the region are part-time farms, they are underrepresented in the accountancy data sample. Because of this, data from 20 part-time farms from regions similar to Hohenlohe were added to the farm sample to provide as suitable basis for representing non-professional farms.

Applying the mentioned up-scaling procedure to the farm data sample resulted in the identification of 24 typical farms for 2000/2001 (Table A-1). Of these, 19 farms operate as full-time, and five as part-time farms. The scaling factor is given in the last row. The selected farms match the characteristics of agriculture in Hohenlohe quite well. In most cases, deviation is be-

[6] A detailed description of the upscaling procedure and underlying data is given in Happe (2004), Sahrbacher (2003) and Kleingarn (2002).

low 5%.[7] For instance, the selected typical full-time farms weighted by the weighting factors manage 57,350 ha land, in reality it is 57,464 ha. The deviation between the adapted model and real regional statistics is largest for specialised crop farms and farms with less than 10 hectares. The reason is that very small farms are underrepresented in the underlying accountancy data sample. Larger differences exist only when smaller farm sizes and livestock capacities are concerned. On the one hand, this is because of a sample error in the German farm accountancy data sample in which particularly small farms are underrepresented in the sample. Thus, it is particularly difficult to represent the many small non-professional farms. Furthermore, these small farms are predominantly specialised crop farms. This explains the deviation with regard to this farm type. Data on prices, production costs, and technical coefficients are taken from standardised data collections which were published by various German government agencies and organisations (e.g. KTBL, Bavarian State Ministry of Agriculture and Forestry). In a final step, the 2800 model farms which are based on the different farming systems are further individualised with respect to the age and kind of buildings, facilities, machinery, and farm location.

4. Scenarios and assumptions

4.1 Policy scenarios

The policies considered are listed in **Table 1**. The first policy, RETPAY, is a factor market policy, that intends to provide an incentive for small and inefficient farms to withdraw from the sector. The reasoning behind this policy must be seen against the structural deficits mentioned before. In fact, in Hohenlohe – as in many regions in southern Germany – large amounts of family-labour are bound in agriculture either in very small farms with labour intensive older technologies, or in non-professional farms. Hence, it could be envisaged that an incentive payment for relatively unproductive farms to withdraw labour from agriculture could lead to overall efficiency increases of farming in the region. The policy is introduced such that an incentive payment is offered to all farms, but only farms willing to withdraw receive the payment.[8] In this scenario, everything else but the introduction of the retirement payment is kept equal, i.e. remaining farms operate under Agenda 2000 policy conditions and get the corresponding coupled direct payments.

[7] Due to space restrictions, the respective table is not shown here. It can be found, however, in Happe (2004).

[8] Unlike retirement programmes offered within the second pillar of the EU common agricultural policy, the payment introduced here is independent of the age of the farmer. The reason is that the policy is directed at marginal farmers in general.

Table 1. Policy scenarios

Abbreviation	Scenario name	Scenario description
REF	**Agenda 2000**	- Full implementation of Agenda 2000 at the end of 2002 - No requirement to manage all land belonging to a farm
RETPAY	**Retirement payment**	- Payment of 10,000 Euros if a farm withdraws from the sector - Leaving farms receive payment for the next 20 periods - Policy environment for active farms is Agenda 2000 - No requirement to manage all land belonging to a farm
PHASEOUT10	**Phasing out of coupled direct payments**	- Linear cut of coupled direct payments as granted under Agenda 2000 over 10 periods - After this, farms operate without subsidies - No requirement to manage all land belonging to a farm
DECOUP	**Fully decoupled single farm payment**	- Each farm household receives a decoupled single farm payment based on the average direct payment paid to a farm during three periods before the policy change - Bound to person of the farmer and legal successor - Single farm payment is granted independent of farming, i.e. it is also paid if a farm leaves the sector, for the next 20 periods after policy change - Farms are required to manage all farmland belonging to a farm at least in a very basic way (cutting)

The second policy option (PHASEOUT10) is a step-wise reduction of direct payments granted to farms over 10 time periods. At the final stage, after 10 periods, support to agriculture is zero. Unlike policy RETPAY, the general direction of adjustment, which could be expected from a step-wise reduction of direct payments, is twofold: on the one hand, farms can be expected to diversify into areas with highest productivity, which are less dependent on direct payments. On the other hand, farms whose development potential is low are expected to not renew fixed assets or rental contracts. Whenever the operating life of fixed assets is reached, these farms are expected to leave the sector.

Finally, the third policy is geared to increasing the market orientation of production while providing a safety net at the same time to farms through direct payments. Policy DECOUP introduces fully decoupled single farm payment granted exclusively to the person of the farmer. The payment replaces the coupled direct payments to certain products granted under Agenda 2000. The single farm payment is granted independently of farming, i.e., production decisions are decoupled from the provision of payments to certain products. The payment is to give farm agents greater flexibility and to increase their market orientation[9]. In this scenario, the single farm payment granted to each farm agent after a policy change is based on historical payments during a reference periods before the policy change. In the literature, a switching to a single farm payment independent of farm activity is expected to have significant effects on fac-

[9] In this paper, the terms farm agent and farm are used interchangeably.

tor markets (see e.g., 1997; Swinbank and Tangermann, 2000; OECD, 1994). For example, a decoupled single farm payment could serve as an incentive payment for marginal farmers to withdraw, particularly because the right for the payment remains with the person of the farmer who initially acquired the payment. Hence, the payment should not be transferred into rental prices but rental prices would be at the level of the economic land rent without subsidies. In addition, it is assumed that the bargaining position of farmers on the land market increases (cf. Isermeyer 2003). To reflect these two aspects in the farm agents' opportunity cost calculations at the end of each period, the specific expectation formation regarding rental prices is changed. As for fully decoupled payments it is assumed that farms expect rental prices (and hence opportunity costs of land) for arable land (grassland) to drop to some 75% (50%) of the regional average[10].

4.2 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**,
- 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.

The policy experiments conducted in the following are based on a number of assumptions:

- **Simulation length:** Each policy scenario is simulated for 25 periods. This appears a sufficiently long time frame to asses short-term, medium-term and long-term effects of a policy. A longer time frame would be interesting only if the long-term behaviour of AgriPoliS was of interest. In this thesis, this is not done, though.
- **Policy change:** Each policy scenario is initialised with the reference policy Agenda 2000. Only after 4 simulation periods, a policy change toward an alternative policy sets in[11].

[10] Different values for the expected decrease of rental prices were analysed as well but the assumed figures appeared to lead to most plausible results.

[11] Following the convention in the C++ programming language, counting starts with zero, i.e. time period t=3 is the

- **Region size:** Although altogether 2800 farms were situated in Hohenlohe in 2000/2001, it proved to be technically infeasible to simulate always the entire regions. The reason was mainly, that output files exceeded the maximum permissible number of rows supported by most analysis programmes (e.g. Microsoft Excel, SPSS). However, Happe (2004) gives some evidence that the size of the region simulated did not have significant impact on results. Although this was not investigated for policy scenarios other than the reference, in the policy experiments, 20% of the total region is simulated. This means that the respective scaling factors derived for each of the 24 typical farms was divided by five such that 572 farms were initialised[12].
- **Prices and variable costs:** Prices are assumed the same for all farms. Unit costs, however, vary between farms depending on managerial ability and technical change due to farm investment activity. Because of the relatively small size of the region and the family farm-dominated structure, it can be expected that farms are price takers[13]. Prices therefore do not change in response to quantities produced. However, a pressure on some output prices was introduced.
- **Price changes:** Product prices as well as prices of short-term variable and fixed labour are assumed to decrease (or in case of labour and capital) increase.
- **Costs of fixed assets:** Once a farm invests, costs of the investment are assumed fully sunk, i.e., opportunity costs are zero throughout the entire useful life of the investment.
- **Education of farm agents:** Farm agents are assumed equally smart with regard to their ability to work off-farm. Moreover, it is assumed that all farmers have the same opportunities to work off-farm, irrespective of age.

5. Results

Although each simulation run produces a large amount of data for each farm agent and time period (e.g., production, rental prices, farm type), in the following analysis we focus on the analysis of size differences between farms, and the development of the total economic land rent in the region as a proxy for the allocation of production factors.

5.1 Analysis of farm size development

The evolution of the total number of farms in the region and the average farm size measured in hectares are shown in **Figure 2**. The figure demonstrates clear differences between policy

fourth time period in the simulation.

[12] Just to illustrate, a full simulation produces output files of up to 80 MB of data.

[13] This assumption has to be loosened if large scale farms are concerned, as these farms are more in the position to negotiate about prices of inputs as well as about output prices.

scenarios. It illustrates that the number of farms withdrawing is particularly large in case of the retirement payment. The suddenly decreasing number of farms indicates that many farms take the retirement payment as an opportunity to leave the sector. Thus, for more than 50% of the farms, an annual payment of 10,000 € results in a higher total household income compared to regular farm activity. Because so many farms withdraw, this offers scope for the remaining farms to grow. **Figure 2** (b) shows that the average farm size doubles immediately after the policy change.

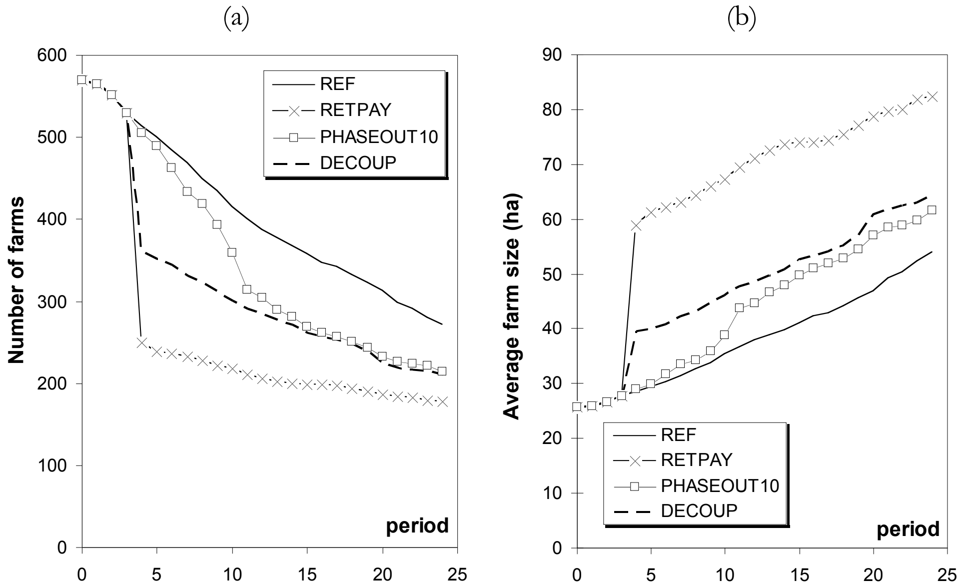

Figure 2. Evolution of (a) number of farms and (b) average farm size

After the initial adjustment reaction, average farm size in scenario RETPAY develops parallel to the reference and the number of farms leaving the sector is even below the reference. This indicates that the policy elicits an immediate and strong initial adjustment reaction, which is followed only by small but nevertheless steady further adjustments after the policy change. Fully decoupled direct payments granted in policy DECOUP have a similar initial effect on the number of farms and on average farm size than a retirement payment, though at a lower level. The fact that farms receive decoupled payments irrespective of agricultural production leads some farms to quit and to take the decoupled single farm payment as a kind of retirement payment. With respect to this, the two policies induce a similar adjustment reaction at the aggregate level.

Nevertheless, there are differences. One difference is that the retirement payment of 10,000 € per year induces more farms to withdraw than a fully decoupled single farm payment. Since in scenario DECOUP there are some farms with a single farm payment smaller than

10,000 € per farm, more farms remain in the sector under policy DECOUP than under RETPAY. In other words, only if expected yields in policy DECOUP are greater than total opportunity costs, but below 10,000 €, the farm would remain in the sector. In policy RETPAY, the same farm would withdraw from the sector. Accordingly, in particular with respect to small farms, policy RETPAY creates a strong incentive to leave the sector as the retirement payment of 10,000 € maybe significantly higher than the single farm payment granted in scenario DECOUP. A second difference is that under policy scenario DECOUP some land is abandoned, i.e., it is not rented by farms.

In scenario PHASEOUT10, the reasons for farms to leave the sector are different than in either policy DECOUP or RETPAY. Farms with insufficient development potential do not reinvest in fixed assets or renew rental contracts; over time they are expected quit. In fact, in scenario PHASEOUT10, which introduces a gradual policy change over 10 periods, farmers need to adjust to gradually decreasing direct payments. Whereas in scenarios RETPAY and DECOUP the retirement payment as well as the decoupled single farm payment pull farmers out of the sector by providing an incentive payment, in scenario PHASEOUT10 farms are pushed out.

One more interesting phenomenon can be observed. The number of farms in scenario PHASEOUT10 is consistently above the number of farms in scenario RETPAY. This suggests that under free-market conditions more farms would remain in the sector than in case of a retirement payment. From this, one could conclude that also farms with a development perspective leave the sector in response to the retirement payment.

5.2 Development of the economic farm size

Farm size in hectares does not give precise information about the economic importance of farms. In particular a comparison of farms based on hectares is not very reliable due to the varying importance of land in different farm types. With regard to analysing and comparing all farms in the region, it is more appropriate to use the economic size. The economic farm size, expressed in European Size Units (ESU), corresponds to the total production valued at standard gross margin[14]. **Figure 3** presents kernel density estimates and the empirical cumulative density function of the economic farm size for four time periods (one period before the policy change and three periods after the policy change). In general, the distribution of farm size in all policy scenarios moves to the right, indicating farm growth. Furthermore, particularly in the medium and long-run, the shapes of the curve are more pronounced for scenarios REF, DECOUP and PHASEOUT10 with peaks appearing at 70 ESU, 110 ESU, and 210 ESU. Hence, clusters of farms with a similar economic sizes emerge. Nevertheless, distributions show differences, particularly if periods are compared.

Figure 3 offers one important observation. Unlike scenario RETPAY, policy scenarios REF, PHASEOUT10, and DECOUP create policy environments that allow for the further

[14] The ESU measure here does not entirely correspond to the one used by the EU since standard gross margins are taken from regional data sources and thus differ from those used by the EU.

existence of small farms, at least in the short-run and in the medium-run. This particular aspect constitutes a major difference between a retirement payment in scenario RETPAY and a decoupled single farm payment. Moreover, it indicates that mainly small farms take up the lump-sum retirement payment and leave the sector, whereas in case of a decoupled single farm payment the threshold to leave the sector depends on the farms' historic size and activity. **Table 2** shows that small farms remaining in the sector react to a policy change to policies PHASE-OUT10, or DECOUP by converting from full-time to part-time farming. Indeed, a decoupled single farm payment provides the ground for mixing income sources in the best possible way as long as this is profitable. The same line of reasoning applies to policy PHASEOUT10, where, as long as coupled direct payments are granted, small farms mix income sources (see **Table 2**). In the long-run, i.e., after 24 time periods, also small farms disappear in scenario DECOUP. However, as small farms disappear in the long-run, it shows that the strategy of mixing income sources is only viable for a limited number of time periods.

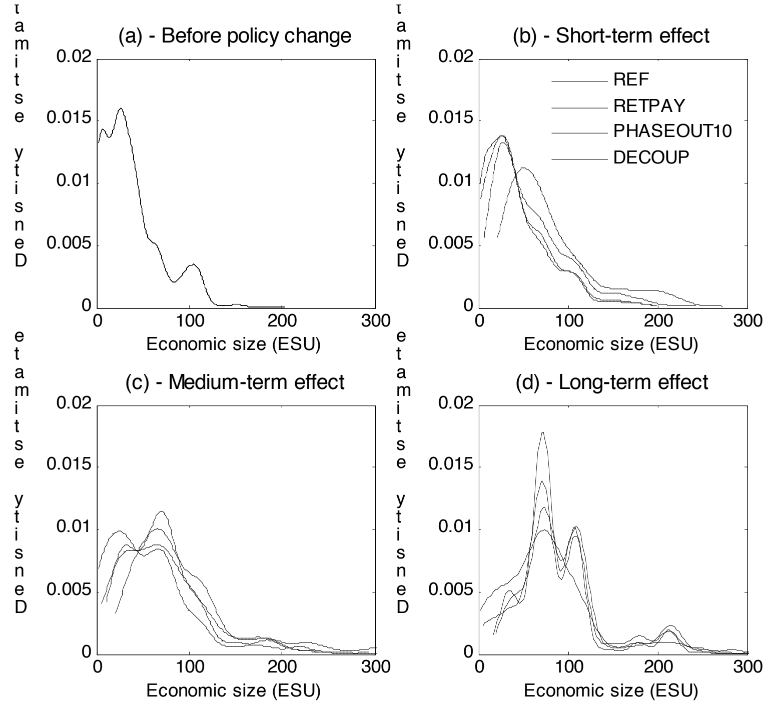

Figure 3. Kernel density estimates of economic farm size

Table 2. Off-farm income share of small farms < 25 ESU[a)]

Time period	REF	RETPAY	PHASEOUT10	DECOUP
Bef. policy change	65% (228)	65% (228)	65% (228)	65% (228)
Short-term	64% (189)	41% (6)	65% (167)	54% (80)
Medium-term	60% (100)	24% (1)	58% (30)	48% (34)
Long-term	47% (41)	28% (2)	90% (3)	42% (15)

Notes: a) Number of farms in parentheses.

5.3 Economic land rent as an efficiency indicator

To assess the allocation of production factors in the region, economic land rent is utilised as an indicator. This is done in analogy to Balmann (1996). Economic land rent is based on the functional income of land. It provides a measure of the residual utilisation of land after all other production factors (labour, capital) have been paid for. If calculated at the individual farm level, economic land rent is an indicator for the utilisation of production factors of the farm. Alternatively, it can be calculated as a regional average which serves as an indicator of factor allocation in the entire region. Here we measure economic land rent as total household income (which corresponds to farm net value added plus off-farm income) less by opportunity costs of capital and farm family labour[15]. Long-term opportunity costs of farm-family labour are valued at the comparative salary of an industrial worker. To draw conclusions about the allocation of all factors in the region, economic land rent is furthermore adjusted by support payments as well as realised sunk costs of farms leaving the sector to take account of productive capital that is no longer used. The economic land rent calculated here takes a long-term perspective because it includes also the costs of fixed assets, i.e. it includes depreciation. In the short-term, depreciation is not considered.

Table 3 gives an overview of the average economic land rent in the region with and without sunk costs of fixed assets. Sunk costs in this respect can be interpreted as adjustment costs. Of course, this also related to the assumption that costs of fixed assets and capital are sunk. Economic land rent in Table 3 furthermore does not include subsidy payments to compare and show how economic land rents would develop if subsidies were removed in any one period.

[15] This adjustment to the way economic land rent is calculated may be justified by the fact that in particular non-professional farms cross-finance farm activity with income earned off-farm. This, in turn, can be interpreted as a household-internal transfer payment, which in the end adds stability to the farm household. On the other hand, all family owned labour, i.e., also labour not used on-farm is considered when opportunity costs of labour are calculated.

Table 3. Comparison of economic land rent including sunk costs and economic land rent without sunk costs excluding subsidies at four time periods

Economic land rent	**REF**	**RETPAY**	**PHASEOUT10**	**DECOUP**
	(€/ha)			
Before policy change (t=3)	-430	-430	-430	-430
without sunk costs	*-319*	*-319*	*-319*	*-319*
Immediately after change (t=4)	-388	-2,360	-437	-1,259
without sunk costs	*-299*	*-112*	*-291*	*-162*
Short-term effect (t=6)	-336	-131	-374	-191
without sunk costs	*-274*	*-97*	*-247*	*-144*
Medium-term effect (t=14)	-194	-49	-108	-71
without sunk costs	*-176*	*-21*	*-63*	*-49*
Long-term effect (t=24)	-104	115	-3	21
without sunk costs	*-73*	*144*	*-60*	*75*
Capital value of economic land rent incl. sunk costs (base: t=3)[a)b)]	-4,021	-2,893	-2,859	-2,638
Ave. annual economic land rent incl. sunk costs[c)]	-221	-159	-157	-145

Notes: a) Interest: 5.5%; b) under the assumption that policy is not terminate; c) computed from capital value of economic land rent.

Three aspects are noteworthy here: First, economic land rent is negative in most time periods (with -430 €/ha in period t=3 before the policy change). This means that the initialised structure with data from the Hohenlohe region is highly inefficient with respect to the allocation of production factors unless subsidies are provided. That is to say, production factors are not necessarily used where productivity is highest. However, with structural change economic land rent increases in all policy scenarios indicating an efficiency increase subject to the assumed price development.

Second, relative to the reference, economic land rent is highest in scenario RETPAY followed by scenario DECOUP. If subsidies were considered, then average economic land rent of policy PHASEOUT10 would be considerably below the other policy scenarios and it would decline when payments are cut successively. However, if subsidies are not included in the calculation, there is step-wise increase in economic efficiency in this scenario, pointing towards a gradual re-organisation of production. In other words, regarding overall efficiency a similar situation is reached with three very different policy measures.

Third, structural adjustment leads to a massive devaluation of asset and human capital as represented by sunk costs. These can also be interpreted as the costs of structural adjustment. Initially, policies RETPAY and DECOUP are very costly in this respect with a negative economic land rent of up to 2,360 € per hectare. Accordingly, a large amount of productive capital is lost by farms leaving the sector. Despite of this short-term effect, farms in policy scenarios RETPAY and DECOUP generate a significantly higher economic land rent in all following periods as compared to the reference. To evaluate the total adjustment costs caused by the policy, the capital value of economic land rents including sunk costs is computed for an infinite number of periods[16]. Results show that capitalised adjustment costs per hectare are highest in scenario REF (-4,021 €/ha), and lowest in scenario DECOUP. (-2,638 €/ha). Hence, compared to all other policies policy DECOUP creates the highest efficiency gains in the long-run which compensate for high adjustment costs incurred immediately after the policy change. This is also reflected in the average annual economic land rent including adjustment costs.

Although the previous figures provided some substantial information on the allocation of production factors together with advantages of individual efficiency, there are drawbacks with using averages. Due to a sample effect, the number of farms as well as the total amount of agricultural land managed by farms changes over time and between scenarios (Figure 2). Therefore, on average, economic land rent may increase, but the direction of change depends on the development of the sample of farms and the amount of land farmed. Furthermore, average economic land rent is calculated from aggregate values, i.e. it does not account for heterogeneity between farms.

6. Discussion and outlook

6.1 Simulation results

In this paper, we focussed on the analysis of three indicators: farm size in hectares, economic farm size, and total regional economic land rent. We have chosen these indicators to highlight the impact of size differences on survival under a policy change. Of course, the analyses we've carried out here, could and probably should have gone more into depth to identify specific adjustment patterns, e.g. of individual farms types. Especially, the kernel density estimation could have been augmented by a test of the difference of densities to underline that the differences we see in the graph are in fact statistically significant.

As expected, policies providing incentives for small farms to withdraw from the sector, lead to significantly larger farms that realise size effects and produce at lower costs. In this sense, all alternative policies, ceteris paribus, have reached their intention. Depending on the definition of the respective policy, the speed of structural adjustment differs substantially between policy scenarios. Taking adjustment costs into account, all alternative scenarios represent overall economic efficiency gains that compensate for adjustment costs. Overall efficiency gains are highest for policy DECOUP. Policies that provide incentive payments cause stronger adjustment reactions right after the policy change (DECOUP and RETPAY) than a policy introducing gradual changes (PHASEOUT10). As for adjustment reactions, farms increasingly specialise and operate as full-time farms, i.e., the decision of farms is increasingly a leave-or-

[16] It is assumed that the policies do not terminate, and the rate of structural change continuous after period t=24 at the average of periods 20 to 24.

stay decision. Part-time farming as an option 'in between' is an adjustment reaction to some farms in the short and medium-run, but it becomes irrelevant in the long-run.
Sudden and hard policy changes (RETPAY and DECOUP) lead to strong reactions on the side of the farms in the short-run. With a large number of farms leaving right after the policy change, the region is more or less consolidated with the remaining sample of farms being comparatively homogeneous. In the periods following the policy change, the heterogeneity of farms continuously increases, as for example the emergence of few but very large farms in the sample shows. In addition, the initial adjustment pressure created by policies RETPAY and DECOUP is strong. Following this, in policy RETPAY the retirement payment provides only little incentives for further structural change. This is fundamentally different in policy scenario PHASEOUT10 and even in the reference. In the latter case, the 'natural' structural dynamics inherent in AgriPoliS provide a constant, but slow adjustment pressure to farms. However, effects similar to a sudden policy change are only visible in the long-run.

6.2 The suitability of AgriPoliS and the assumptions made

A core component of this study was the development and application of the agent-based model AgriPoliS. 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 have to be interpreted and questioned against the assumptions made. For example, AgriPoliS rests upon the rather strong assumption of profit maximisation determining the behaviour of farms, as well as specific assumptions about agent interactions and certain parameter values. 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 of 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 (cf. Happe, 2004) show plausible results compared to actual empirical observations and economic reasoning. In addition, obtained results are in line with results obtained from simulation experiments carried out before this study using AgriPoliS or precursors of AgriPoliS and they match empirical observations such as slow structural change, persistently unexploited economies of scale, and income disparities (Balmann 1999).

Regarding the application presented in this paper, several assumptions appear especially relevant. **First**, AgriPoliS assumes economies of scale and technological change by way of lower costs, which can be realised by all farms in the region by investing in assets, respectively. This assumption is in accordance with empirical observations on cost digressions (e.g., Kuhlmann and Berg, 2002) as well as theoretical considerations. **Second**, we assume that the rural labour market is capable of taking up all excess labour from agriculture as well as to meet farms' demand for hired labour. **Third**, farms face high sunk costs, as opportunity costs of farm-owned production factors are low, or zero in the case of fixed assets (cf. Balmann 1995). Yet, one should not forget that opportunity costs between farms are heterogeneous and depend, e.g., on education and mobility. **Fourth**, rather moderate differences in the managerial ability of farms were assumed. That is, unit production costs of farms with high managerial ability and farms with low managerial ability differed by a 10% maximum. In reality, production cost differences between individual farms are potentially much larger. **Fifth**, labour-saving technical change and the assumed increase in costs of hired labour were considered comparatively low. Finally, **sixth**, as for off-farm labour opportunities, there are no differences in skills of individual farmers, i.e., farmers are equally smart and capable to work off-farm.

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 extending 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[17].

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 conduct intensive test periods at each new development step. This also extends to the implementation of different policy scenarios. Overcoming the shortcomings of 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

Baffes J. (2004): *Experience with Decoupling Agricultural Support*, Rod Ziemer Lecture, University of Georgia, April 14, 2004.

Balmann A. (1995): *Pfadabhängigkeiten in Agrarstrukturentwicklungen – Begriff, Ursachen und Konsequenzen*, Duncker und Humblot, Berlin.

Balmann A. (1996): "Struktur-, Effizienz- und Einkommenswirkungen direkter Einkommenstransfers and landwirtschaftliche Betriebe", *Schriften der Gesellschaft für Wirtschafts- und Sozialwissenschaften des Landbaues* e.V., 32: 361-372.

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

Balmann A., Happe K. (2001): "Agentenbasierte Politik- und Sektoranalyse – Perspektiven und Herausforderungen", *Agrarwirtschaft*, 50 (8): 505-516.

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

Bankes S. (1993): "Exploratory Modeling for Policy Analysis", *Operations Research*, 41 (3): 435-449.

Beard N., Swinbank A. (2001): "Decoupled payments to facilitate CAP reform", *Food Policy*, 26: 121-145.

Berger T. (2004): "Agentenbasierte Modellierung von Landnutzungsdynamiken und Politikoptionen", *Agraœrwirtschaft*, 53 (2): 77-87.

[17] 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. But, 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.

Dewbre J., Antón J., Thomson W. (2001): "The Transfer Efficiency and Trade Effects of Direct Payments", *American Journal of Agricultural Economics*, 83 (5): 1204-1214.

Fennell R. (1997): *The Common Agricultural Policy: Continuity and Change*, Clarendon Press, Oxford.

Ferber J. (1999): *Multi-Agent Systems: An Introduction to Distributed Artificial Intelligence*, Addison-Wesley, Redwood City.

Franklin S. and 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: 21-35.

Gilbert N. and Troitzsch K. (1999): *Simulation for the Social Scientist*, Open University Press, Buckingham.

Goddard E., Weersing A., Chen K. and Turvey C.G. (1993): "Economics of Structural Change in Agriculture", *Canadian Journal of Agricultural Economics*, 41: 475-489.

Hanneman R. and 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. (2004): *Agricultural policies and farm structures – agent-based modeling and simulation*, IAMO Studies on the Agricultural and Food Sector in Central and Eastern Europe.

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)*, IAMO Discussion Paper 71.

Isermeyer F. (2003): "Umsetzung des Luxemburger Beschlusses zur EU-Agrarreform in Deutschland – eine erste Einschätzung", Arbeitsbericht 03/2003, Institut für Betriebswirtschaft, Bundesforschungsanstalt für Landwirtschaft, Braunschweig-Völkenrode, http://www.bw.fal.de (in German).

Jennings N.R., Sycara K. and Wooldridge M. (1998): "A roadmap of agent research and development", *Autonomous Agents and Multi-Agent Systems*, 1: 7-38.

Kleingarn A. (2002): *Anpassungskosten von Agrarpolitikänderungen – Erstellung und Kalibrierung der Datengrundlage für ein räumlich-dynamisches Multiagentenmodell der Region Hohenlohe*, Diplomarbeit, Humboldt Universität zu Berlin (Master thesis in German).

Koester U. and Tangermann S. (1976): *Alternativen der Agrarpolitik, Eine Kosten-Nutzen-Analyse im Auftrag des Bundesministeriums für Ernährung*, Landwirtschaft und Forsten, Landwirtschaftsverlag, Münster-Hiltrup (in German).

Kuhlmann F. and Berg E. (2002): *The Farm as an Enterprise – The European Perspective*, 13th International Congress of Farm Management, July 7-12, 2002, Papendal Conference Center, Arnhem.

Luck M., McBurney P., Preist C. and Guilfoyle C. (2003): *Agent Technology: Enabling Next Generation Computing – A Roadmap for Agent Based Computing*, AgentLink II, Retrieved from internet: November 2003, www.agentlink.org.

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: 63-74.

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

OECD (1994): *Agricultural Policy Reform: New Approaches – The role of direct income payments*, Paris.

OECD (1995): *Adjustment in OECD Agriculture – Issues and Policy Responses*, Paris.

Parker D.C., Berger T., Manson S.M. and 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.

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: 261-272.

Russel S. and Norvig P. (1995): *Artificial Intelligence: A Modern Approach*, Englewood Cliffs, NJ.

Sahrbacher (2003): *Modellierung der Agrarstruktur Hohenlohes auf der Grundlage typischer Betriebe – Bereitstellung der Datengrundlage für das agentenbasierte Modell AgriPoliS*, Diplomarbeit, Universitaet Hohenheim, Stuttgart (Master thesis in German)

Swinbank A. and Tangermann S. (2000): "A Proposal for the Future of Direct Payments Under the CAP", Working Paper No. 1 prepared under the Project "Bond Scheme" financed by the EU Commission (QLRT-1999-015010).