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Research, part of a Special Feature on Empirical based agent-based modeling

Agent-based Analysis of Agricultural Policies: an Illustration of the Agricultural Policy Simulator AgriPoliS, its Adaptation and Behavior

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ABSTRACT. This paper combines agent-based modeling of structural change with agricultural policy analysis. Using the agent-based model AgriPoliS, we investigate the impact of a regime switch in agricultural policy on structural change under various framework conditions. Instead of first doing a sensitivity analysis to analyze the properties of our model and then examining the introduced policy in an isolated manner, we use a meta-modeling approach in combination with the statistical technique of Design of Experiments to systematically analyze the relationship between policy change and model assumptions regarding key determinants of structural change such as interest rates, managerial abilities, and technical change. As a result, we observe that the effects of policies are quite sensitive to the mentioned properties. We conclude that an isolated analysis of a policy regime switch would be of only minor value for policy advice given the ability of simulation models to examine various potential futures.

Key Words: *agent-based modeling; agricultural policy analysis; empirical-based simulation; experimental design; farm structures; meta-modeling.*

INTRODUCTION

Agricultural economics supports the decision-making process in agricultural policy making by providing concepts, procedures, and data to policy makers. The goal of quantitative agricultural policy analysis is to study the impact of agricultural policies on a range of indicators, e.g., income, prices, farm size, efficiency, factor allocation, production, welfare, etc. at different levels of scale, e.g., at the global, national, sector, regional, or farm scale. A recent example that clearly demonstrates the demand for agricultural policy analysis and decision support is the 2003 reform of the European Union's Common Agricultural Policy (CAP; EU Commission 2003). The reform is characterized by a substantial switch of the support system. One key reform element is the so-called decoupling of support from production. Under the previous system (Agenda 2000), farmers received payments for producing certain products such as cereals. Under the new system, which began in 2005, payments are decoupled from production. This means that farmers now receive payments that are based on historical sums and are independent from production. These payments should not influence any current activity of the farmers (OECD 2005). Many researchers consider decoupled payments to distort markets less than more traditional market and quota policies (e.g., Lewis and Feenstra 1989, OECD 1994, 2001, Swinbank and Tangermann 2000, Beard and Swinbank 2001, Dewbre et al. 2001, Baffes 2004).

Policy impact analysis is a complex modeling problem at the farm and regional scale, primarily for two reasons. First, agricultural policies influence the decision making of individual farms and their actions on product markets and factor markets. Second, farms are heterogeneous with regard to a range of attributes like factor endowments, ownership structure, location, farm management, and the competitive position on markets for products and production factors. Depending on these attributes, possible adjustments to changing framework conditions may be manifold, ranging from adjusting the product mix or making investment or disinvestment decisions, to changing the income mix between on and off-farm income sources. Moreover, farms may also react by withdrawing from the sector. However, some of these attributes, such as investments in specialized

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assets that can only be used to produce a specific product, may create barriers to exiting and hinder farms from adjusting.

Agent-based simulation offers a conceptual framework to approach this modeling problem because it facilitates capturing heterogeneity between agents as well as dynamics. Because agent-based models follow a bottom-up approach, they are able to capture the process of structural change endogenously. This property makes agent-based models suitable for modeling structural change processes. Agent-based models are in direct contrast to other well-known modeling approaches in agricultural policy analysis such as general or partial equilibrium models, which carry out policy impact analysis at a higher level of aggregation. These model's capabilities of accounting for individual adjustment reactions are limited.

This paper combines agent-based modeling of structural change with agricultural policy analysis. Using the agent-based model AgriPoliS, we investigate the impact of a regime switch in agricultural policy on structural change under various framework conditions. The policy switch takes place from the old policy Agenda 2000 to a specific form of decoupled support: the introduction of a single area payment scheme (SAP), which attaches a uniform hectare payment to all agricultural land. We adjust AgriPoliS to the agricultural structure of the Hohenlohe region, a family-farming region in southwest Germany.

Not only do we vary the policy setting independently, but we also explore the model's policy impact sensitivity regarding variations in other model inputs that represent important drivers of structural change. For this, we use the statistical techniques of Design of Experiments (DOE) and meta-modeling (e.g., Law and Kelton 1991, Kleijnen and van Groenendaal 1992). This particular approach allows us to systematically conduct simulation experiments with different input parameter constellations to discover relationships between model inputs and the corresponding output. Inputs reflecting key drivers of structural change in the model and in the literature are technological change, macroeconomic framework conditions, e. g., interest rates, policy environment, and socioeconomic characteristics of the farm operator, e.g., managerial ability, (see e.g., Weiss 1999, Glauben et al. 2003).

The structure of the paper is as follows: the next section introduces the agent-based model AgriPoliS. We then present the study area Hohenlohe. The following section introduces sensitivity analysis using DOE and meta-modeling and specifies the experimental design and meta-model. This is followed by a presentation of the sensitivity analysis results and further investigations on the impact of the policy switch on structural change. We conclude with a discussion of results and the methods applied in this paper. An appendix, including a detailed documentation of the used agent-based model, supports the paper.

THE AGENT-BASED MODEL AGRIPOLIS

Conceptual framework

The core of Agricultural Policy Simulator (AgriPoliS) is the understanding and modeling of an agricultural system as an agent-based system (Russel and Norvig 1995, Franklin and Graesser 1997, Jennings et al. 1998, Ferber 1999, Gilbert and Troitzsch 1999, Luck et al. 2003, Parker et al. 2003, Tesfatsion, *unpublished manuscript*). The model establishes a virtual world of an agricultural region and comprises a large number of individually acting farms that operate in a region, as well as farms' interactions with each other and with parts of their environment. The modeler can fully control the rules of the model. AgriPoliS is a further development of a model originally developed by Balmann (1997) to study path dependencies in structural change. Whereas the original model was based on an abstract agricultural region, AgriPoliS provides interfaces to initialize the model with empirical data on individual farms and existing regional agricultural structures. In the following, we present a basic overview of the model; Appendix 1 gives additional technical details and a more thorough description. Those interested in the model code may directly contact the authors.

Figure 1 depicts the model's conceptual framework of a regional agricultural system. In brief, this can be described as consisting of the three key factors: the farms in a region, the landscape the farms are situated in, and the markets for inputs and outputs. To transfer this concept into an agent-based simulation model, each farm in the region is represented by an agent that is an entity that acts individually, senses parts of its environment and acts upon it. For that purpose, each farm agent is equipped with a behavioral model that guides decisions and keeps track of the agent's internal state described by attributes such as age, location, or factor endowments. According to their behavioral model, the individual farm agents evolve subject to their actual state and to changes in their environment. In AgriPoliS, this environment consists of three parts: the direct environment of a farm consisting of other farms located in the same region, the spatial context in which the farms are located and which at the same time serves as the land input to agricultural production, and markets for the necessary inputs and produced outputs of agricultural production. These three main groups of entities themselves are embedded in the general technological and political environment. The following section gives a more precise description of the single entities as listed above and describes the relationship between these entities.

The farm agent

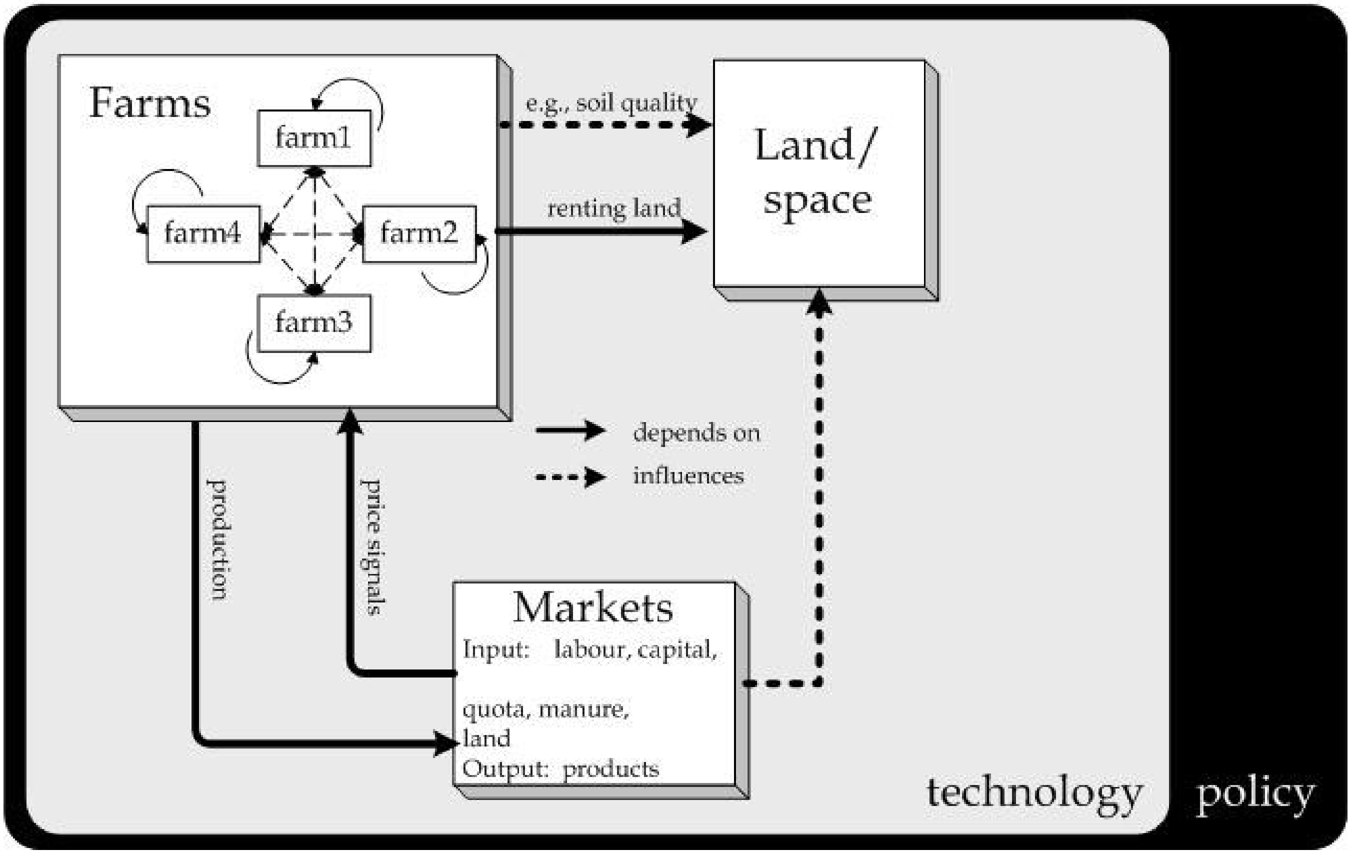
The main element of a farm agent is its behavioral model. This determines a farm agent's decision-making process by selecting a suitable action out of the available action space contingent on the farm agent's current internal state and the state of its environment. The internal state of a farm agent is organized as a balance sheet, which keeps track of factor endowments, the farm's age, expectations about future prices, as well as a number of financial indicators and changes as a result of the farm agent’s actions. Although one of the attractions of agent-based models is that they can accommodate a range of different behavioral types, the farm agent's behavioral model is based on neoclassical production theory. Accordingly, a farm agent's decisional rule is to maximize household income. This assumption is reasonable for agricultural enterprises in Western Europe, where farming systems that follow different behavioral objectives such as subsistence farming play only a minor role.

Mixed-integer programming provides a means of implementing the behavioral model by deciding on the income maximizing combination of production activities and investment choices with respect to a set of farm resource constraints (cf., Hazell and Norton 1986). From one period to the next, resource constraints in the mixed-integer program are updated based on previous decisions on investments, production, and farm exit. Farm agents decide exclusively based on their own situation and on expectations about prices and policies; expectations about the behavior and actions of other agents are not included. Expectations are limited and not rational in that they are based on adaptations to errors made during previous periods. To summarize, even though farm agents optimize at the individual level, their decision-making process can be referred to as myopic because the decision problem of farm agents is highly simplified compared to real decision problems.

In order to characterize a farm agent's action space, we distinguish between standard production activities, auxiliary activities, investment activities, and the decision to continue farming. For farm production, a farm agent can engage in a range of production activities. In order to produce, the agent uses different production factors, e.g., land, buildings, machinery, liquid capital, labour of different types and capacities. The auxiliary activities are: land rental activities, production quotas, and manure disposal rights. A farm agent can also hire labour on a fixed or on a per-hour basis; vice versa, a farm’s family labour can be offered for off-farm employment (for details see Appendix 1). To finance farm activities and to balance short-term liquidity shortages, farm agents can take up long-term and/or short-term credit. Unused liquid assets are invested at the assumed savings rate. To get a detailed overview on the possible actions of a farm, see Appendix 1.

Regarding investments in fixed production factors, we assume economies of size, i.e., the fixed costs per unit decline as the size of the investment grows. The magnitude of these is based on technical calculation data as published, for example, by the Board of Trustees for Technology and Structures in Agriculture in Germany (cf., KTBL 2004). Moreover, larger investments are associated with a lower labour input per unit produced. As for investments in fixed assets, in agricultural production, many activities require specialized assets that cannot be diverted to other uses, i.e., the opportunity costs of such assets are zero. Examples of highly specific assets are hog production operations or investment in agricultural training. In these cases, investment costs in such activities are said to be sunk because they cannot be recovered on second-hand markets. In AgriPoliS, we assume all investment costs to be sunk costs. New investments affect production capacities for the useful life of the investment. Investment costs are depreciated over the entire useful life of the

Fig. 1. Conceptual framework of AgriPoliS.



investment. Balmann (1999) showed that sunk costs are a major cause of path dependence in structural change. If, on the contrary, all costs were variable costs, then farms could adapt perfectly by flexibly selling assets and recovering parts of the investment costs. This would speed up structural change (Balmann et al. 2006).

Based on expected returns for the next year, farm agents decide whether to exit or stay in the sector. It is rational for a farm agent to exit if its equity capital is zero, the farm is illiquid, or if farm-owned production factors such as land, family labour, and working capital would earn a higher income outside farming. In the latter case, the opportunity costs of farm-owned production factors would not be recovered by farming activity.

After a farm agent has reached a certain age, a generational change takes place. In case of such a generational change, we generally assume that for each farm agent there is a potential successor. However, for a successor to take over, the farm has to generate at least as much income as a comparable job outside farming. We assume that in this case the opportunity costs of labour are as high as the earnings from off-farm labour, which are taken from macroeconomic statistics.

Landscape

AgriPoliS models space in a stylistic way by implementing some, but not explicit, spatial relationships, such as the share of land of a particular type. Space is represented by a set of equally sized cells/plots assembled into a chessboard–like pattern. Similar to a GIS, several attributes are associated with each of these plots: soil type, ownership, e.g., owned by farm agent, rented, plot state, e.g., idle land not managed by a farm agent, plot in use, rent paid by farm agents, plot size, and transportation costs to the respective farm managing the plot. In this paper, we distinguish between three different types of land, namely arable land, grassland and nonagricultural land, The latter represents natural borders such as forest, roads, etc.

Product and factor markets

AgriPoliS agents interact indirectly by competing on factor and product markets. Direct interactions between agents, for example, to negotiate rental contracts bilaterally, are not considered. Interaction on markets is organized by market agents that explicitly coordinate the allocation of scarce resources such as land or the transaction of products. Markets for products, capital, and labour, are coordinated via a price function with an exogenously given price elasticity and a price trend associated with each product.

The land market is the central interaction institution between agents in AgriPoliS and is fully endogenous to the model. To understand the central role of the land market in the model, it is useful to know that because of the immobility of land, agricultural land markets are highly localized markets. Unlike markets for capital and products, on which farmers are price takers, prices for land result from local interactions between farmers or farmers and landowners. This is particularly relevant for regions with a high livestock production where farm growth is not independent of a farm's hectare base because land provides the basis for fodder production or manure disposal. In AgriPoliS, farm agents extend their hectare base exclusively via renting land. Regarding land ownership, in AgriPoliS there are farm agent landowners and external, nonfarming landowners. The latter are not modeled explicitly but they rent out their land to farm agents. In the former situation, all land is either owned or rented by farm agents. When AgriPoliS is run, land available for rent on the rental market stems from two sources: one is farms that have ceased production and withdrawn from the sector, the other is land released to the market due to terminated rental contracts.

The land market in AgriPoliS is organized as a sequential auction that allocates free plots in the region to farms wishing to rent these plots. In brief, the land allocation process works as follows. To allocate free land to farms, AgriPoliS implements an iterative auction during which an auctioneer, a market agent, allocates free plots to farm agents that intend to rent additional plots of land. First, each farm agent produces a bid for a particular plot of land. The bid depends on the farm agent's marginal income for an additional plot of land, i.e., shadow price for land, the number of adjacent farm plots, and the distance-dependent transportation costs between the farmstead and the plot. Second, the auctioneer allocates a free plot to the farm agents with the highest bid. This procedure is repeated until all free land is allocated or if bids are zero.

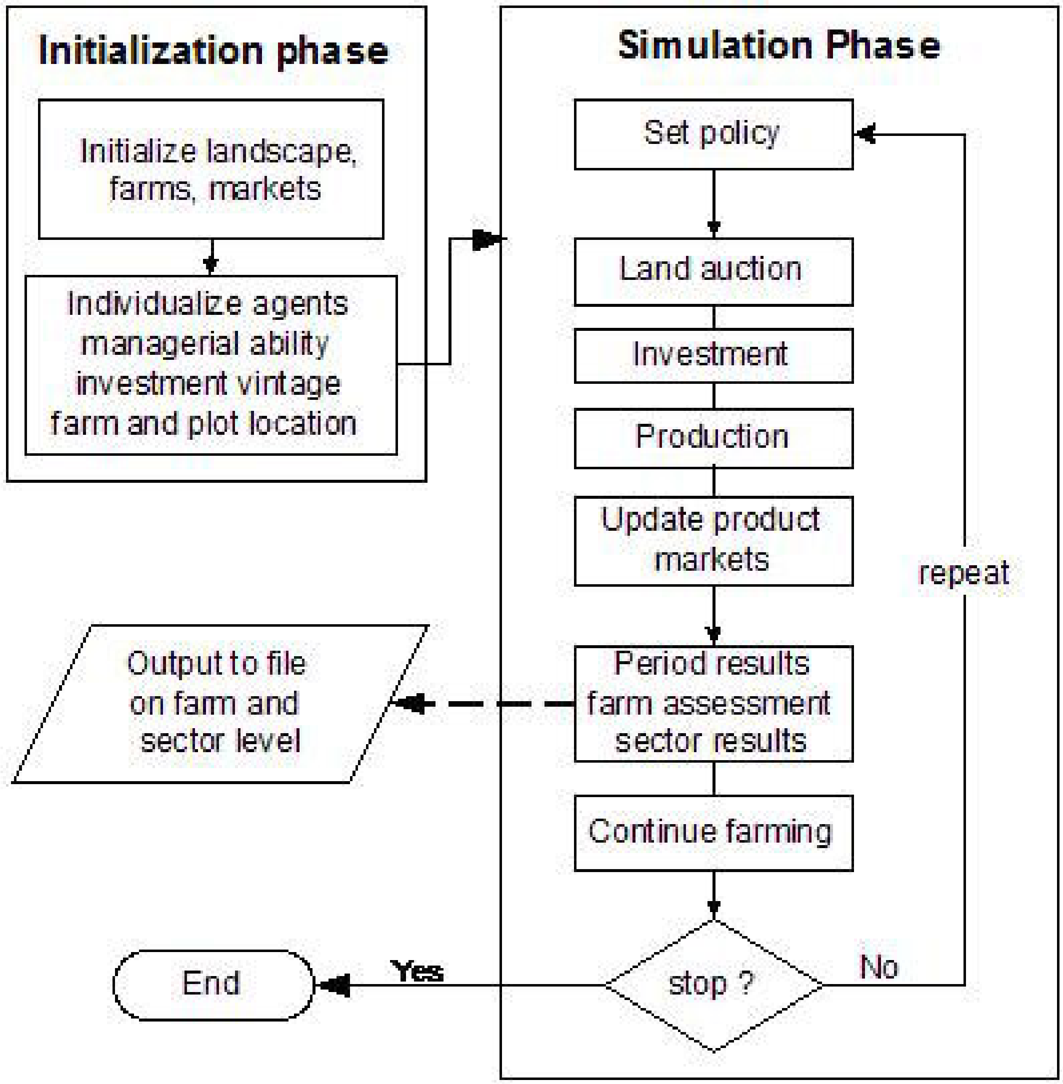
Technological and political environment

The technological environment is given by technologies of different residual useful lives and technological standards. We assume production technologies to progress over time. However, this is created in the upstream sector, but not on the farms themselves. Farm agents can benefit from technological progress by realizing additional cost savings when adopting new technologies. General economic framework conditions such as interests for capital and agricultural policies define the farm agent's general and political environment. Agricultural and environmental policies affect the farm at different instances such as prices, stocking density, and direct payments, whereas general economic framework conditions enter AgriPoliS via interest rate assumptions.

Model flow and interfaces

Figure 2 provides an overview about the dynamics of the model and the course of events during one simulation period. AgriPoliS has an interface to a spreadsheet file that includes data on the regional agricultural structure in order to initialize the model. The file contains data on individual farm agents, e. g., family labour, machinery, buildings, production facilities, land, production quota, liquid assets, and borrowed capital, regional data, e.g., number of farms, farm types, total land, and stylized data on technical coefficients, prices, and costs. On the output side, AgriPoliS compiles aggregate data at the sector level, on the one hand, and individual farm data on the other. More specifically, data output at the sector and farm levels include data listed in Table 1.

Fig. 2. Model dynamics and course of events during one period.



EMPIRICAL ADAPTATION AND MODEL INITIALIZATION

The study region Hohenlohe, southwest Germany

We adapted AgriPoliS to the agricultural structure of the Hohenlohe region located in southwest Germany. The region proved to be suitable for this study as it is characterized by diverse agriculture with intensive livestock production, e.g., hog finishing, sows for breeding, and turkeys, on the plains (Fig. 3a), and dairy and forage production in the valleys (Fig. 3b).

Although there are good soils, especially on the plains, crop and forage production dominate. In 1999, Hohenlohe comprised about 73,439 ha of agricultural area, managed by approximately 2869 farms (Statistisches Landesamt Baden-Württemberg 1999). Approximately half of the farms were run as full-time farms, with the remaining farms being part-time farms. Full-time farms, due to their larger average farm size of 36.4 ha, with an average size

Table 1. Data output at farm and sector levels.

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/	Total capital input	€
	full-time	Total labor	h
Owned land	ha	Investment	
Rented land	ha	Investment expenditure	€
Production		Economic land rent	€/ha
Output in quantities	ha, LU	Sector totals of farm level data	various units
Output in value	€		
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 labor	
Variable costs	€/unit	Labour input	h
Subsidies		Family labor	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	€		

(con'd)

Total land assets	€
Liquidity	€
Borrowed capital	€
Short-term borrowed capital	€

of part-time farms of 11.3 ha, cultivated 66% of the agricultural area in Hohenlohe. All included farms were family farms, the members of which carried out more than 97% of the on-farm labour. The livestock production played a major role in Hohenlohe (Table 2).

Creating an empirically based virtual farm structure for AgriPoliS

Creating an empirically based virtual farm structure for AgriPoliS focuses on two issues: one is to match the starting conditions of AgriPoliS with Hohenlohe's structure in the base year 2000/2001. The other is to specify the farm agent's mixed-integer programming model to represent the organization of a set of farms typical for the region. Regarding the first point, we initialized AgriPoliS with a virtual farm structure that provides a close approximation to observed regional characteristics for Hohenlohe in the base year. Examples of regional characteristics are the number of farms in a size class, total factor use, acreage of various products, overall livestock numbers, or total output of relevant products. Regarding the second point, we used farm level data from the European Farm Accountancy Data Network (FADN) to represent individual farm agents. FADN is a microeconomic database containing information on agricultural holdings in EU member states such as physical and structural data, e.g., crop areas and livestock numbers, as well as economic and financial data for farms, e.g., production costs, factor input, and subsidies.

Since the FADN farm sample is not representative of the farming structure in the study region, a particular aggregation scheme is necessary to select a number of “typical farms” and to define weights for each of these farms in order to best represent regional characteristics. To select the typical farms, the chosen selection procedure simultaneously (1) reduces the number of farms from a given individual data list, e.g., FADN, and (2) gives each farm a weight, whereby the weights denote the number of times a typical farm has to be located in the region such that the agricultural structure of the region is best represented (Sahrbacher et al. 2005). The selection procedure is formulated as a quadratic optimization problem, which minimizes the quadratic deviation between the virtual farm structure and the observed region according to a number of regional characteristics.

Applying this procedure to the Hohenlohe FADN dataset for the financial year 2000/2001, we derived a set of typical farms consisting of 19 full-time farms and five part-time farms and the according weights for each farm (Table 3). The resulting virtual farm structure matches the regional characteristics of agriculture in Hohenlohe quite well (Table 4). In most cases, the deviation is less than 5%. The deviation between the adapted model and regional characteristics is largest for specialized crop farms and farms with less than 10 ha. The deviation for farms less than 10 ha is -14.04%, and for specialized crop farms is 13.56%. Larger differences exist only when smaller farm sizes and livestock capacities are concerned. The reason is that very small farms are underrepresented in the underlying FADN sample. Thus, it is particularly difficult to represent the many small part-time farms. In addition, these small farms are predominantly specialized crop farms, and this explains the deviation with regard to this farm type.

Initializing AgriPoliS with the virtual farming structure

Having identified the typical farms for our region, AgriPoliS is initialized. For this, we further individualize the farms in three steps. First, we create identical copies of each typical farm according to its weight. Second, we randomly allocate each farm agent in the region. Regarding

Fig. 3. Examples of farming in Hohenlohe (a) on the Hohenlohe plains, (b) in the valleys Source: http://www.schwaebischhall-online.de.

this assumption, the reader may wonder why we do not represent the region's true neighborhood relations. The answer is that besides data protection with regard to the exact location of farmsteads and plots in the regions, Happe (2004) found that model results are robust against random variations and therefore also against the location of a farm (Happe 2004). However, as mentioned before, we introduce some true statistical relationships such as the share of land types in the virtual region. Thirdly, farms agents are randomly individualized with respect to managerial ability, farm age, and the age structure of assets.

STUDYING THE LINK BETWEEN A POLICY SWITCH, DETERMINANTS OF STRUCTURAL CHANGE, AND MODEL SENSITIVITY

Using designed experiments to investigate the sensitivity of AgriPoliS

Although AgriPoliS may map key components of the agricultural structure in Hohenlohe, it obviously cannot capture the complexity of the agricultural system of Hohenlohe fully. Inevitably, guesses and assumptions about the true nature of the region, referred to as the target system, have to be made and implemented into AgriPoliS. Moreover, when building the model, we do not know the way in which, or to what extent, certain assumptions influence model output. At the same time, the model itself is so complex that even simple interactions between parts of the model can lead to model behavior that cannot be anticipated in advance, even by the modelers. In agent-based models, these emergent properties can be especially crucial (cf., Axelrod 1997). If we want to draw relevant policy conclusions based on an analysis of interactions between policy measures and determinants of structural change implemented in the model, we have to consider both the model assumptions and interaction effects. To reveal these relationships in a structured way, we apply a formal sensitivity analysis.

The goal of sensitivity analysis is to determine which input variables within a set of input variables in the model have important effects on the output (van Groenendaal and Kleijnen 2002). Unfortunately, even with complex simulation models, sensitivity analyses are often done in an unstructured way, e.g., by simply varying only one factor at a time (Manson 2002, Kleijnen et al. 2003). This so-called "one-at-a-time" approach leaves out possible interactions between input variables, i.e., the effect of individual input variables is not independent of each other.

Table 2. Farm structure in Hohenlohe in 1999. †UAA stands for used agricultural area in hectares.

Farm types	All farms		Full-time farms		Part-time farms	
	Farms(%)	UAA†(%)	Farms(%)	UAA(%)	Farms(%)	UAA(%)
Total	100	100	100	66	100	44
Specialized crop	15	12	7	4	25	9.5
Grazing livestock	30	29	30	20.5	30	9.2
Intensive livestock	34	38	41	26.4	24	9.9
Mixed	17	20	20	14	14	5.1
Permanent crops	5	0.4	1.6	0.2	8	0.3

To circumvent this drawback, we use the statistical techniques of Design of Experiments (DOE) and meta-modeling (e.g., Box et al. 1978, Kleijnen and van Groenendaal 1992, Vonk Noordegraaf et al. 2002, Montgomery 2005). In the context of agent-based models, Kleijnen et al. (2005) have found DOE to be a useful technique because it can help to uncover details about a model's behavior, help to identify the relative importance of input variables, provide a common basis for discussing simulation results, and help to identify problems in the program logic.

Although it is not feasible to simulate all possible combinations of input variables, especially in the presence of continuous input variables, a range of factor levels for every input variable in DOE, i.e., in the domain called factor, is defined. Although this leads to a significant reduction of possible combinations, even with a small number of factors and factor levels for each factor, it is not possible to simulate all combinations. A specific subset of all possible combinations is chosen to further reduce the number of combinations. This subset is called experimental design which still allows, because of its special properties as discussed later on, to analyze the effects of factor level changes on model output. Besides a graphical analysis, this can be done by response surface models, or meta-models, that statistically approximate the relationship between factors and responses, e.g., with regression models (van Groenendaal and Kleijnen 2002, Sanchez 2005).

Application of Design of Experiments and meta-modeling to the Hohenlohe case study

Five factors are chosen for exploring the Hohenlohe dataset. Although this represents only a small subset of all AgriPoliS inputs (cf., Appendix 1), we expect these factors to have a strong influence on structural change because they affect the way in which farm agents use their factors of production. The five factors follow (details on where factors affect AgriPoliS are given in Appendix 1):

1. The percentage decrease of unit production costs after a new investment. This factor acts as a proxy for the impact of technological change (TC) on farms when adopting new technologies. The extent of the cost-saving effect depends on the technical standard and size of the investment. Larger objects generate higher unit cost savings.

2. Unit costs of production differ between farm agents, reflecting different levels of heterogeneity in managerial ability (MA). We assume that farmers with better management capabilities operate at lower unit production costs relative to standard production costs;

3. The interest rate on short-term and long-term borrowed capital for financing investments (IBC). Interest rates for borrowed capital

Table 3. Full factorial design matrix for 25 possible factor combinations: (-) denotes low factor level, (+) denotes high factor levels. †SC stands for specialized field crop farm, GL for grazing livestock farm, SG for Intensive livestock farm, and MI for Mixed farm based on German classification before 2002 with a threshold at 50% of total standard gross margin. ‡ Land endowment is adjusted to fit a plot size of 2.5 ha assumed in AgriPoliS. Source: Sahrbacher et al. (2005).

	Full-time farms																		**Part-time farms**					
Number	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Specialization†	SG	SG	SG	SG	SG	SG	SG	SG	GL	GL	GL	GL	GL	GL	SC	SC	MI	MI	MI	SG	SG	GL	SC	MI
Land [ha] ‡																								
Total	55	20	50	35	32.5	15	35	55	30	90	32.5	37.5	15	30	77.5	30	20	50	42.5	17.5	25	15	10	10
Arable land	55	20	50	35	32.5	15	35	55	12.5	57.5	10	10	10	22.5	77.5	30	20	50	27.5	17.5	25	10	10	5
Grassland	-	-	-	-	-	-	-	-	17.5	32.5	22.5	27.5	5	7.5	-	-	-	-	15	-	-	5	-	5
Rented land	32.5		37.5	7.5	7.5	2.5	17.5	35	10	67.5	17.5	25	5	5	52.5	15	-	-	25	2.5	5	5	-	10
Equity capital [1000 €]	905	457	714	949	687	427	518	980	455	773	558	516	208	493	322	449	681	1,121	239	454	444	326	326	38
Family labor [1000 h]	4.1	2.9	3.1	3.5	3.5	2.6	3.1	3.2	1.7	3.9	3.3	2.7	2.6	2.6	2.6	1.9	2.3	4.1	1.8	3.4	3.0	3.0	1.9	3.2
Livestock [head]																								
Beef cattle	-	-	-	-	-	-	-	-	-	-	10	10	-	-	-	-	-	-	-	-	-	15	-	-
Suckling cows	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	15	-	-	-	-	-
Dairy cows	-	-	-	-	-	-	-	-	25	65	40	30	10	14	-	-	-	-	-	-	-	-	-	7
Sows	110	45	128	128	130	55	80	200	-	-	-	-	-	22	50	-	150	75	50	25	-	-	-	-
Fattening pigs	800	-	260	160	-	-	-	25	-	-	-	-	-	-	-	140	-	-	25	30	430	-	-	-
Turkeys	-	-	5500	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Milk quota [1000 L]	-	-	-	-	-	-	-	-	143	371	228	171	57	80	-	-	-	-	-	-	-	-	-	-
Weights	49	178	83	42	67	94	13	72	140	41	111	101	122	63	52	20	110	140	109	183	59	295	449	263

Table 4. Comparison of regional characteristics and initial virtual farm structure based on typical farms. One livestock unit corresponds to about 500 kg of live weight. Source: Sahrbacher et al. (2005).

Indicators	**Regional characteristics**	**Initial AgriPoliS farm structure**	**Deviation**
Farms	**2869**	**2857**	**-0.42%**
Incl.: Specialized crop farms	459	521	13.56%
Grazing livestock farms	906	873	-3.66%
Intensive livestock farms	988	951	-3.74%
Mixed farms	516	512	-0.82%
Full-time farms	1553	1607	3.50%
Part-time farms	1316	1250	-5.05%
Agriculturally-used area (ha)	**73,439**	**73,587**	**0.20%**
Incl.: Arable land	57,468	59,034	2.72%
Grassland	15,971	14,553	-8.88%
Agriculturally-used area by farm type (ha)			
Incl.: Specialized crop farms	9569	9143	-4.45%
Grazing livestock farms	21,683	23,408	7.95%
Intensive livestock farms	27,766	26,774	-3.57%
Mixed farms	14,421	14,261	-1.11%
Full-time farms	57,464	57,350	-0.20%
Part-time farms	16,276	16,237	-0.24%
Agricultural holdings (holdings) with an agriculturally used area of ... to under ... ha			
1-10	828	712	-14.04%
10-30	981	1042	6.22%
30-50	630	666	5.71%
50 and over	430	437	1.68%
Production structure (head) number of livestock kept in stocks of ... to under ... head			
Fattening pigs	*106,008*	*106,074*	*0.06%*
under 100	9541	10,007	4.89%
100-200	9541	9519	-0.23%

(con'd)

200-400	22,262	21,635	-2.81%
400-600	25,442	25,531	0.35%
600 and over	39,223	39,382	0.41%
Sows	*101,122*	*104,452*	*3.29%*
under 30	6067	10,643	75.41%
30-50	8090	8022	-0.84%
50-100	25,281	24,740	-2.14%
100 and over	61,684	61,047	-1.03%
Dairy cows	*17,667*	*17,562*	*-0.59%*
under 20	4063	3942	-2.99%
20-29	3533	3502	-0.90%
30-39	3003	3032	0.94%
40-59	4417	4445	0.64%
60 and over	2650	2641	-0.33%
Beef cattle	*50,902*	*48,006*	*-5.69%*
Turkeys	*450,000*	*461,227*	*2.49%*
Livestock units (LU) [†]	**117,839**	**120,146**	**1.96%**

mainly influence investment decisions and short-term financing activities;

4. The policy environment (POL). This factor mainly deals with the type and level of payments granted to farm agents; and

5. The interest rate on equity capital (IEC).

We defined two levels for each factor around a default value (Table 5), which represents our standard simulation configuration to which the model has been calibrated (for default levels of other model inputs, see Happe 2004 Chapter 4). The low and high values coded as (-) or (+) are based on expert opinion, statistical data, and plausibility arguments. Factors not included in the DOE are assumed to remain at their default level during the simulations. The reasoning behind the chosen factor levels is as follows. At the low factor level for TC, we consider a situation without technological change, i.e., we assume that new technologies have no influence on production costs. At the high factor level, farms can realize cost savings when adopting new technologies. Factor MA represents the heterogeneity in managerial ability across farms. Due to the lack of empirical data, the assumed default support range of ± 5% variation of the variable production costs is uncertain. Therefore, we look at a situation with no heterogeneity in managerial ability and one in which the variable production costs are uniformly distributed between ± 10%. Factor IBC comprises two factors: interest on long-term borrowed capital and interest on short-term borrowed capital. We vary both factors in the same way; that is, we consider a situation with a low interest rate level and a high interest rate level. We assume the same for factor IEC.

Regarding factor POL, we consider a switch from the default policy Agenda 2000 toward a decoupled

Table 5. Factor level settings with low (-), default, and high (+) factor settings. Note: † Cost savings; †† Cost savings support range around standard production costs. IBC stands for interest on borrowed capital, IEC stands for interest on equity capital, MA stands for cost savings due to managerial ability, POL stands for the policy scenario, and TC stands for technological change.

Factor		Description	(-)	default	(+)
1	TC	Technological change†			
		Large-scale investments	0%	1.5%	2%
		Medium-scale investments	0%	1.25%	1.5%
		Small-scale investments	0%	1%	1%
2	MA	Heterogeneity in managerial ability††	0%	± 5%	± 10%
3	IBC	Interest on long-term borrowed capital	3.5%	5.5%	7.5%
		Interest on short-term borrowed capital	6%	8%	10%
4	POL	Policy environment	Agenda 2000	Agenda 2000	REGPREM
5	IEC	Interest on equity capital	2%	4%	6%

policy (REGPREM). Agenda 2000 assumes a continuation of the Dommon Agricultural Policy (CAP) as it was valid until the end of 2004. This means that direct payments are granted for the production of specific crops and livestock. Thus, it generates some production incentive and directs the allocation of production factors to those activities that are eligible for support. Scenario REGPREM implements a so-called single area payment scheme, which is similar to what a number of EU countries have opted for in response to the 2003 CAP reform. Under policy REGPREM, a farm agent can claim a payment for each managed plot of land. This payment is calculated based on the average total payments granted to all farm agents over the three time periods prior to policy change in the region. To receive the payment, farm agents are not required to produce, but they are required to manage land in the most basic way, e.g., cutting grass. This specific requirement does not hold for the Agenda 2000 policy. In this way, it is interesting to observe how this realistic switch toward a new political framework is affected by other nonpolitical framework conditions as represented by the remaining four factors.

From the (-) and (+) factor level settings in Table 5, we constructed a 2^k full-factorial design matrix comprising all possible 2^5 factor combinations or scenarios (Table 6). Although the design represents only two discrete levels for each factor, it has several useful properties. First, it allows us to examine more than one factor at a time. In addition, the design is orthogonal, i.e., the pairwise correlation between any two-factor levels is equal to zero (Sanchez 2005). This full-factorial design allows us to fit regression meta-models including all factor interactions (Kleijnen et al. 2005), yet it provides only a very coarse and linear estimation of the true underlying response surface. Nevertheless, 2^k designs are easy to generate, plot, and analyze, which provides a good starting point for more detailed analyses (Kleijnen et al. 2005). A regression model fitted to this design can thus point in the direction of a factor effect and factor interactions but it does not allow us to capture the full range of complex model behavior.

Out of the model outputs at the sector level generated by AgriPoliS (Table 1), we chose the average economic land rent as our response

Table 6. Full factorial design matrix for 25 possible factor combinations: (-) denotes low factor level, (+) denotes high factor levels. IBC stands for interest on borrowed capital, IEC stands for interest on equity capital, MA stands for cost savings due to managerial ability, POL stands for the policy scenario, and TC stands for technological change.

Scenario	**Factors**				
	TC	MA	IBC	POL	IEC
1	-	-	-	-	-
2	-	-	-	-	+
3	-	-	-	+	-
4	-	-	-	+	+
5	-	-	+	-	-
6	-	-	+	-	+
7	-	-	+	+	-
8	-	-	+	+	+
9	-	+	-	-	-
10	-	+	-	-	+
11	-	+	-	+	-
12	-	+	-	+	+
13	-	+	+	-	-
14	-	+	+	-	+
15	-	+	+	+	-
16	-	+	+	+	+
17	+	-	-	-	-
18	+	-	-	-	+
19	+	-	-	+	-
20	+	-	-	+	+
21	+	-	+	-	-
22	+	-	+	-	+
23	+	-	+	+	-
24	+	-	+	+	+

(con'd)

25	+	+	-	-	-
26	+	+	-	-	+
27	+	+	-	+	-
28	+	+	-	+	+
29	+	+	+	-	-
30	+	+	+	-	+
31	+	+	+	+	-
32	+	+	+	+	+

variable. The rationale behind this indicator is that with the amount of available land fixed, the economic land rent provides information on how well, or efficiently, the other factors of production, e.g., capital and labour, have been used, on average, by the farms. Economic land rent is often used as a measure of the efficiency of factor allocation. For example, think of a situation in which economic land rent in period t is greater than in period t^{-1}. Given that land is fixed, the higher economic land rent suggests that either labour or capital, or both, have been used more efficiently from one period to the next.

The length of the simulation experiment is guided by the actual programming period of the CAP, which runs from 2005 through 2013. Accordingly, we simulated 14 periods altogether, starting in the base year 2000/2001. As for the policy change implemented in factor 4 (POL), the policy REGPREM sets in after four simulation periods. This is because the policy REGPREM is based on historical payments over a period of 3 yr. Furthermore, this reflects the actual setting of the policy, which was introduced in 2005.

AgriPoliS implements some stochastic elements; sources of stochasticity in the model are the farm agent age, asset vintage, the distribution of factor MA, and the location of farm agents in space, which generate the confidence intervals shown in the figures in the next section. To account for these sources of stochasticity, we replicated each of the 32 design points five times. This small number of replications seems justified, as the simulations results seem quite robust against the random initializations. The respective standard errors are displayed as error bars in the results figures.

Based on the experimental design (Table 6), we estimated a regression meta-model in which k denotes the number of factors in the experiment, $X_1, ..., X_5$ denote the coded factors and Y denotes the response variable economic land rent. The 2^5 design enables the estimation of all 26 parameters of fifth-order polynomials. However, we agree with Kleijnen (2004), who argues that higher order effects are hard to interpret and negligible in magnitude. We thus specified the following second-order polynomial regression model:

$$Y = \beta_0 + \sum_{i=1}^{5} \beta_i X_x + \sum_{j=1}^{4} \sum_{j<i}^{5} \beta_{ij} X_i X_j + \varepsilon \quad (1)$$

where the β_j represents the main effects of factor Xi, and β_{ij} as the two-factor interaction effect between factors X_i and X_j.

Using ordinary least squares (OLS), the regression meta-model was fitted to data from three distinct simulation periods (t = 3, t = 5, and t = 13) and to the response variable, average economic land rent, to detect differences between the effects in different time periods. We chose these periods because of the specific nature of the policy change that sets in after four simulation periods. Hence, t = 5 describes a situation immediately after a policy change, whereas an analysis at t = 13 gives some information about long-term effects. We chose a stepwise OLS estimation procedure that automatically excludes all

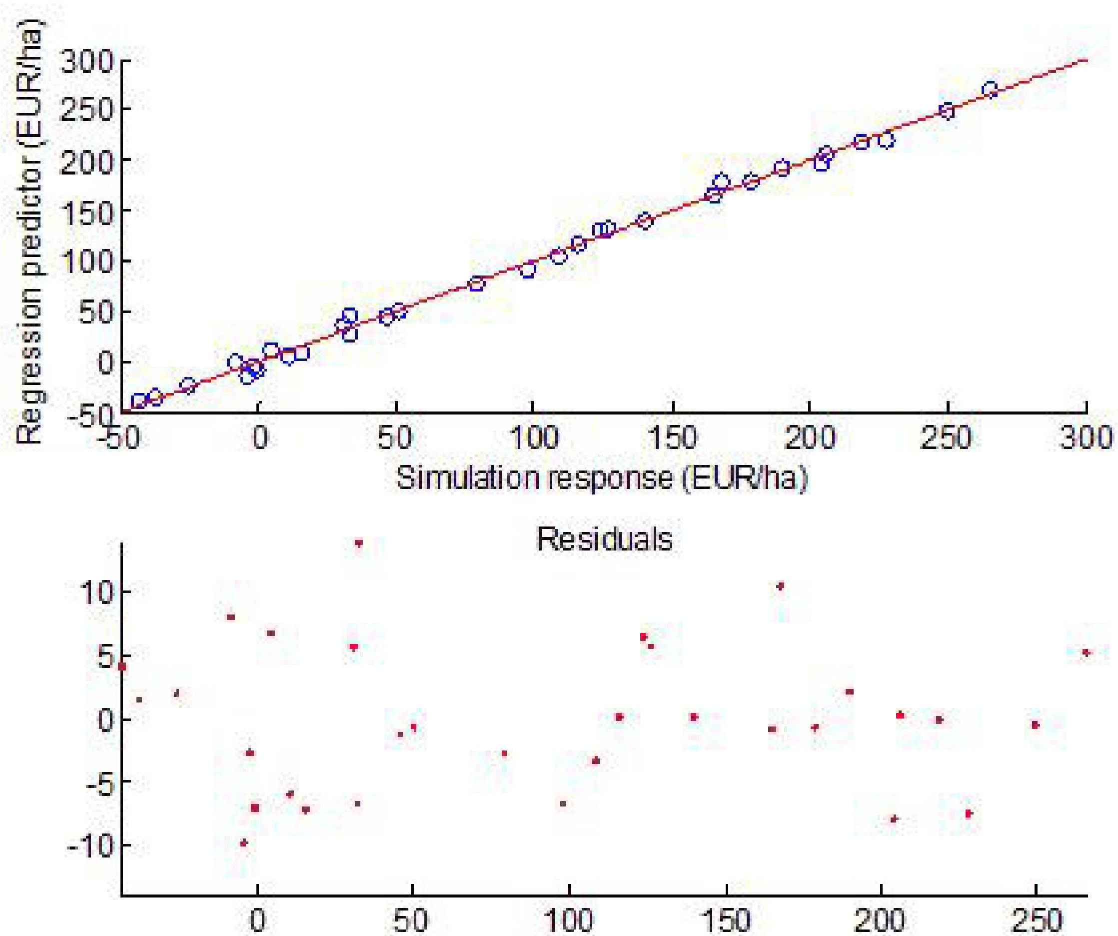
Table 7. Significant factor effects ($P < 0.05$) and 95% confidence intervals based on stepwise OLS regression of simulation design for simulation periods t = 3, t = 5, and t = 13. The response variable is the average economic land rent. IBC stands for interest on borrowed capital, IEC stands for interest on equity capital, MA stands for cost savings due to managerial ability, POL stands for the policy scenario, and TC stands for technological change.

	t = 3			t = 5			t = 13		
	Estimate	95% CI low	95% CI high	Estimate	95% CI low	95% CI high	Estimate	95% CI low	95% CI high
Const	-53.540	-54.561	-52.518	-11.459	-12.496	-10.421	92.786	91.422	94.151
TC	5.792	4.770	6.813	7.361	6.324	8.399	13.563	12.199	14.9279
MA	4.901	3.879	5.922	6.562	5.525	7.599	15.040	13.6759	16.404
IBC	-71.453	-72.475	-70.432	-62.102	-63.139	-61.064	-31.827	-33.191	-30.462
POL				6.570	5.533	7.608	12.684	11.319	14.048
IEC	-82.742	-83.763	-81.720	-81.172	-82.210	-80.135	-81.369	-82.734	-80.005
TC x MA	1.077	0.055	2.098	1.850	0.813	2.887	4.049	2.685	5.413
TC x IBC	-3.949	-4.970	-2.927	-4.266	-5.303	-3.228	-2.775	-4.139	-1.411
TC x IEC	-2.623	-3.644	-1.601	-3.099	-4.136	-2.062	-4.304	-5.668	-2.940
MA x IBC	-2.125	-3.146	-1.103	-1.434	-2.471	-0.396			
MA x IEC	-2.533	-3.554	-1.511	-3.590	-4.627	-2.553	-3.940	-5.304	-2.576
IBC x POL									
IBC x IEC	1.022	0.001	2.043	3.478	2.441	4.515	10.134	8.770	11.498
POL x IEC	1.102	0.080	2.123	2.856	1.819	3.894	4.878	3.513	6.242
adj. R^2	0.996			0.996			0.991		

nonsignificant factors and factor interactions with $P \leq 0.05$. Results in this procedure do not differ from general OLS, which includes all factors and interactions, significant or not. The fit of the meta-model was evaluated using the adjusted R^2.

To test whether the meta-model provides adequate predictions, we also carried out a leave-one-out cross-validation procedure (see Efron 1993, Vonk Nordegraaf et al. 2002, Kleijnen 2005). Cross-validation is a method for testing the generalization abilities of an estimated model. It uses the fitted meta-model to predict the outcomes of new parameter combinations and to compare these predictions with the corresponding simulation responses (Kleijnen and Sargent 2000). The idea behind cross validation is that a dataset is divided into discrete test and training datasets. The training dataset is used to estimate the model and the test dataset is used to test the quality of the model on so far “unseen” data. To avoid a selection bias while dividing the dataset into the test and training datasets, the cross-validation procedure is used. In the context of this paper, cross-validation is carried out in the following way:

Fig. 4. Scatterplot of metamodel predictions and simulations response based on cross validation and plot of residuals for period t = 13.



1. Deleting one scenario and its replications from the complete set of 32 scenarios shown in Table 6;

2. Recomputing the OLS estimator of the meta-models\' regression parameters β while leaving out one scenario and its replications;

3. Substituting the regression parameter, which results from Step 2, for the regression parameter in the meta-model specification provides the regression predictor for the scenario deleted in Step 1;

4. Executing the preceding steps for all scenarios supplies 32 predictions; and

5. These predictions are compared with the corresponding average simulation output of five replications in a scatter plot. We measured the performance of predictions obtained through cross-validation in relation to simulation output using the Pearson linear correlation coefficient.

All regression analyses and cross-validations were done using Matlab R14 SP2 and the Matlab statistical package.

Studying the impact of a policy switch on structural change

Following the meta-model analysis, we then graphically explore the impact of the policy switch on structural change over time with a focus on the default factor levels. To account for the structural change effect, in addition to economic land rent, we also analyze regional averages of four other indicators of structural change: farm size, sunk costs, rental prices for land, and profit/ha of farmland. We look at sunk costs because it is an informative criterion for the cost of adjustment associated with structural change. In this sense, sunk costs represent the total asset value, which is no longer used because of structural change.

SIMULATION RESULTS

Meta-model analysis

The result of the meta-model analysis is shown in Table 7, which reports only significant factor effects at the 95% confidence level. All main effects are significant and have the same sign. Depending on the observed time period, there are seven significant two-factor interactions in each period. In all periods, the adjusted R^2 is high. Model fit was also confirmed by an analysis of residuals and cross-validation, which are nearly normally distributed.

Whereas a factor level change of the factors technological change (TC), managerial ability (MA), and policy (POL) from their low to their high levels has a positive impact on average economic land rent, a factor level change of the factors interest on borrowed capital (BC) and interest on equity capital (IEC) have a negative effect on their response value. That is, a switch from low to high interest rates for either factor IBC or factor IEC results in lower economic land rent in t = 3 and t = 5. For example, in period t = 3, a change in the interest on borrowed capital from the low level, i.e., 3.5% for long-term and 6% for short-term credit, to the high level, i.e., 7.5% for long-term and 10% for short-term credit, on average, decreases economic land rent in the region by 82 EUR/ha. As for factor importance, a change in interest rates has the strongest impact on the simulation response. Factor interaction effects are smaller than main effects. A simultaneous factor level change, for example, for technological change (TC) and the heterogeneity in managerial ability (MA) leads to an increase in economic land rent by 4.059 EUR/ha in t = 13. A high factor level for TC and MA is associated with higher cost savings, which transfer into economic land rent. An exception is the interaction between factors IBC and IEC. Whereas a factor level change of either factor reduces economic land rent, the interaction effect of both factors is positive. Hence, a self-reinforcing effect can be observed.

Cross-validation of the linear regression model

Applying cross-validation, we observe the correlation between the simulation realizations and the meta-model predictions (Fig. 4). For the three periods, the Pearson linear correlation coefficients are 0.9978 (t = 3), 0.9976 (t = 5), and 0.9946 (t = 13), indicating a high predictive quality of the meta-model.

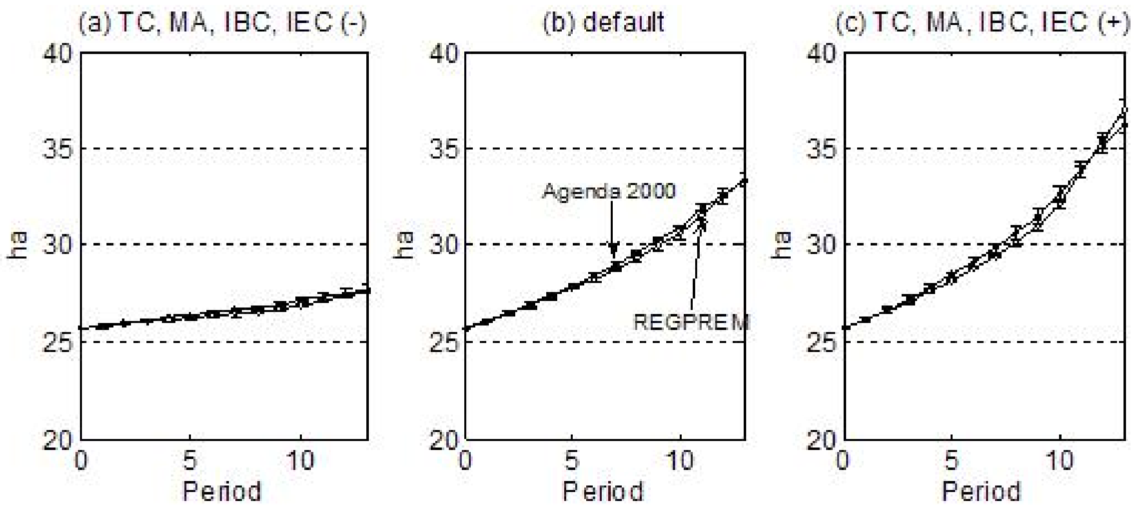
The impact of policy switch on structural change

Having identified the influence of key simulation parameters, in the next step we analyze the development of structural change indicators in response to a change from Agenda 2000 to the decoupled policy REGPREM. Here, we analyze three scenarios based on factor levels in Table 5: in scenario (1) factors MA, TC, IEC, IBC are at their low levels; scenario (2) assumes the default factor levels; and scenario (3) sets factor levels MA, TC, IEC, IBC at their high levels. Scenarios (1) and (3) are called corner scenarios as they describe the boundaries of the analyzed input parameter space.

Compared to the corner scenarios, average farm size in the default setting approximately doubles over 25 simulation periods (Fig. 5b). Irrespective of the parameter setting, the single area payment REGPREM has no significant impact on average farm size. Thus, policy REGPREM, on average, leads to a more similar average structure in terms of farm size than does Agenda 2000, although the distribution of farms within the group may vary. For higher interest rates, and a higher impact of technological change as simulated in scenario (3), structural change speeds up when compared to the default.

If we ask how efficiently factors of production have been used by the farms across scenarios, at first

Fig. 5. Evolution of average farm size over 14 simulation periods and two policies, i.e., Agenda 2000 and the decoupled policy (REGPREM) for low factor levels (-), default, and high factor levels (+). Averages of five replications and standard errors. IBC, is interest on borrowed capital, IEC, interest on equity capital, MA, cost savings due to managerial ability, and TC, for technological change.



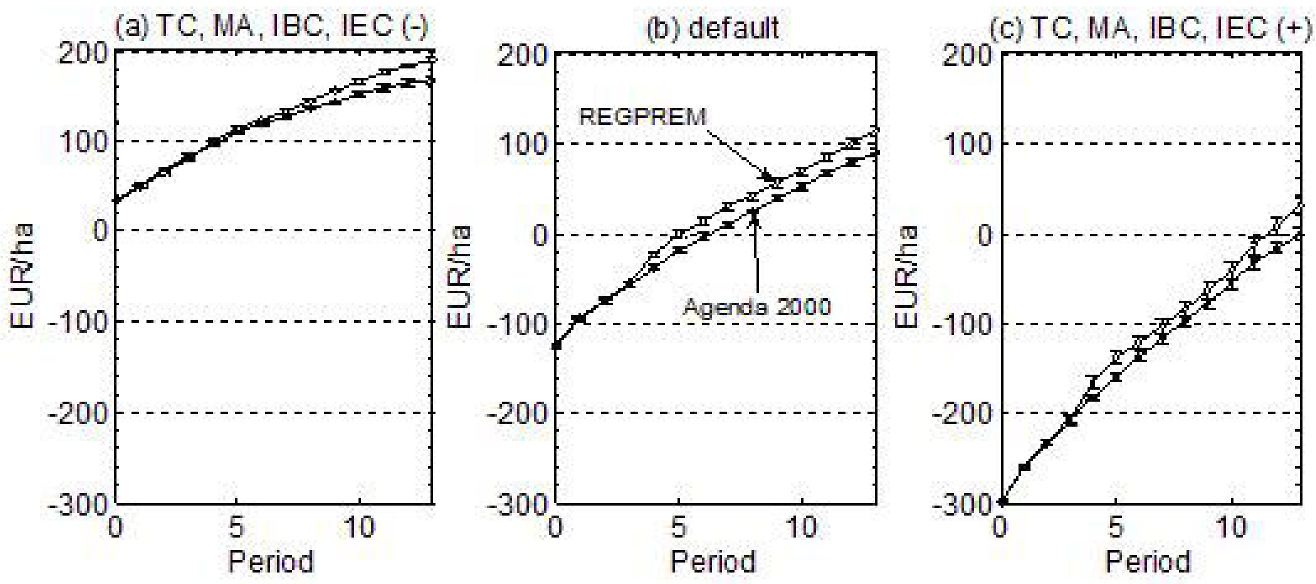
glance, we observe that lower interest rates on borrowed capital and equity, as well as a more homogeneous structure with respect to managerial ability and technological change; scenario (1) leads to a relatively higher level of economic land rent (Fig. 6). Hence, under these conditions, it is worthwhile for farm agents to use the production factors' labour and capital within agriculture. The same conditions also produce a relatively constant structure in which adjustment costs as represented by sunk costs are low (Fig. 7). In scenarios (2) and (3) adjustment costs are higher due to higher interest rates and more heterogeneous farms with regard to managerial ability and technological change. Under these more competitive conditions, initial factor allocation is lower, indicating some inefficiencies in factor use, but shows a stronger increase compared to scenario (1). Even though a policy switch to REGPREM does not substantially change average farm size, it moderately improves the efficiency of factor allocation (Fig. 6). This is also confirmed by results from the meta-model analysis (Table 7).

A change in the structure of direct payments, as implied by policy REGPREM, also changes the development and level of rental prices (Fig. 8). Whereas under Agenda 2000, direct payments are granted only to crop production activities using arable land, under REGPREM all land, including grassland, receives the single area payment. The increasing rental price, thus, reflects the capitalization of payments in grassland values. On average, however, efficiency gains and the single area payment do not fully compensate for lower profits due to higher rental prices (Fig. 8). The sharp decline of average profits right after the policy change also results from another phenomenon. Under Agenda 2000, some land in the region, e.g., grassland, was not in use and rented by farms. REGPREM, on the other hand, creates an incentive to manage grassland at least in the most basic way. The base land used to calculate the average profits/ha is thus higher in REGPREM than in Agenda 2000.

DISCUSSION AND CONCLUSION

Decoupling support is a major element of the most recent package of reforms of the EU Common Agricultural Policy. In this paper, we developed and

Fig. 6. Evolution of average economic land rent and sunk costs/ha over 14 simulation periods and two policies, i.e., Agenda 2000 and the decoupled policy (REGPREM) for low factor levels (-), default, and high factor levels (+). Averages of five replications and standard errors.

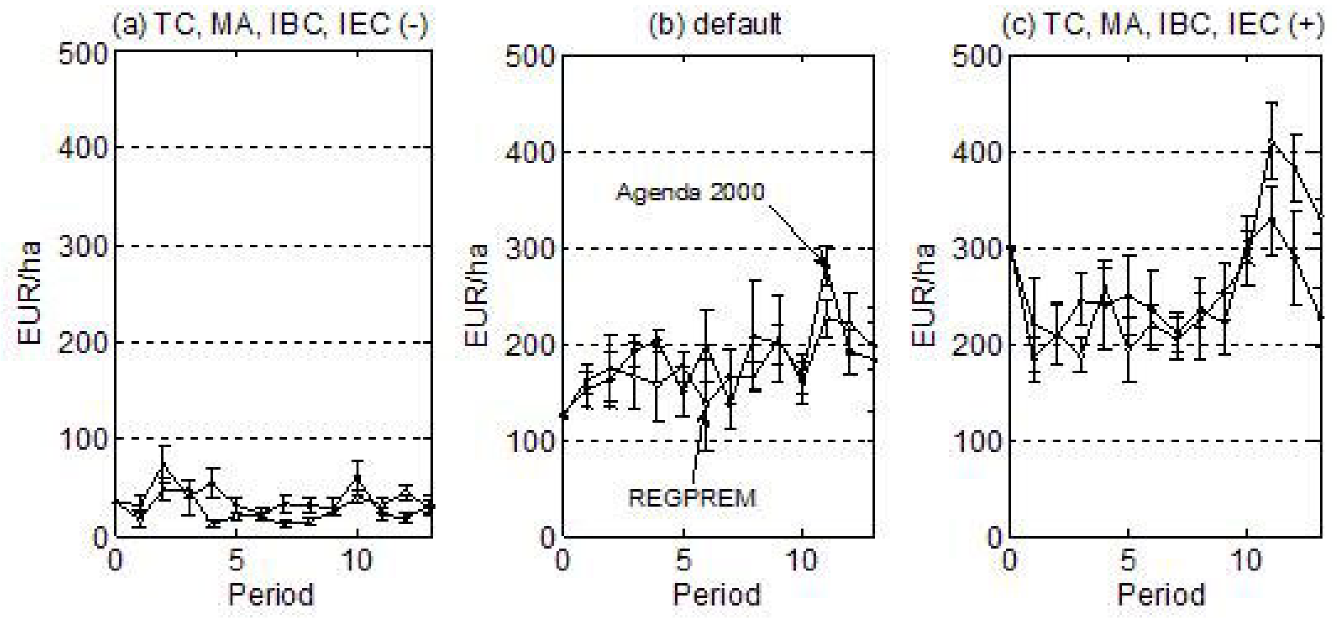


applied the agent-based model AgriPoliS to investigate the impact on structural change of a policy switch from payment coupled to production (Agenda 2000) to a decoupled single area payment. In particular, we were interested in the magnitude of the impact under varying model parameters that represent key determinants of structural change. After adjusting the model to the farming structure of the Hohenlohe region in southwest Germany, simulation results show that if payments are no longer attached to production, but instead to land use only, the agricultural structure is, on average, hardly affected. Adjustment costs after introducing a single area payment do not differ greatly from the reference policy Agenda 2000. However, compared to the reference policy Agenda 2000, the single area payment represents a shift in the payment structure, as grassland is also directly eligible to receive payments. This shift is reflected in the further capitalization of support in higher rental prices, which transfer into lower profits despite a slight efficiency gain.

To systematically investigate the link between a policy switch, determinants of structural change, and model sensitivity, we used the statistical techniques of Design of Experiments and meta-modeling to carry out simulation experiments based on a simple full-factorial design for two factor levels. Although we included only five factors in the simulation design, keeping everything else at the default level, the impact of the significant factors showed that a deeper analysis is indeed meaningful, in particular, with respect to the identification of factor interaction effects between policies and other model parameters. We measured this using the average economic land rent indicator.

Results showed that assumptions about interest rate levels meaningfully influenced the level of economic land rent. If interest rates for borrowed and equity capital are low, relatively more capital is bound in agriculture, which is reflected in higher economic land rent. The reverse was the case if interest rates were at their high level. In this situation, economic land rent and investment activity were low. Introducing heterogeneous managerial ability, in addition to cost savings due to technological change, positively influenced economic land rent. Over time, the impact of these

Fig. 7. Evolution of sunk costs per hectare over 14 simulation periods and two policies, i.e., Agenda 2000 and the decoupled policy (REGPREM) for low factor levels (-), default, and high factor levels (+). Averages of five replications and standard errors. IBC is interest on borrowed capital, IEC, interest on equity capital, MA, cost savings due to managerial ability, and TC, technological change.

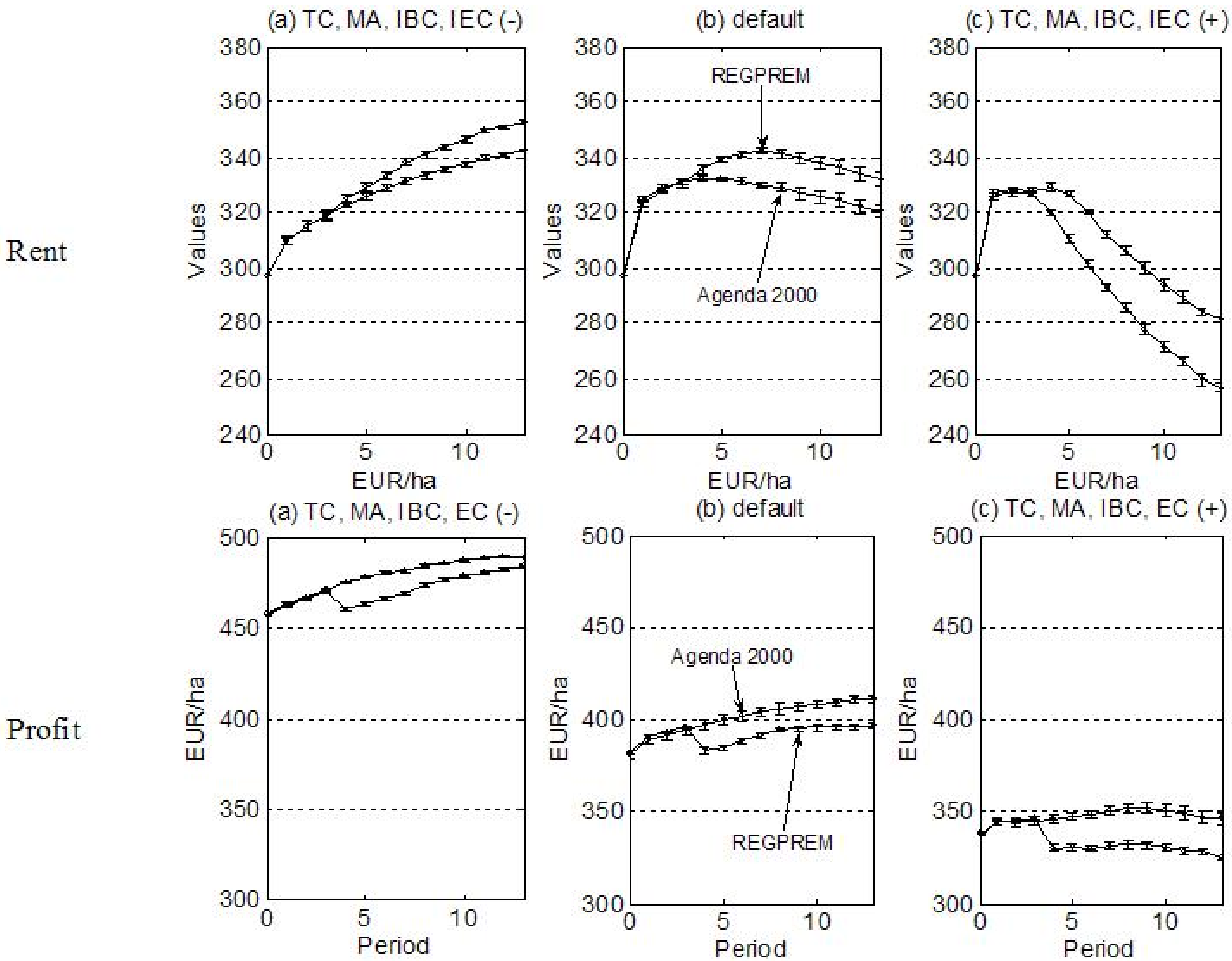


factors increased, pointing toward a greater diversity of farms with respect to the technology used.

A problem of Design of Experiments (DOE) is that no defined rules for appropriate factor level settings are given. Because of this, the importance of factors is partly based on what is defined in the experimental setup. In the extreme, if a narrow range is imposed on an important factor, but a wide range on an unimportant factor, then the latter could turn out to be more important than the former (Vonk Noordegraaf et al. 2002). Similarly, care is required when extracting conclusions from the meta-model to the real system (Vonk Noordegraaf et al. 2002); this inevitably depends on how well the simulation model represents the true underlying system.

AgriPoliS aims to map the basic structure of an agricultural system and its evolution over time, from an economic point of view. Although this paper did not explicitly focus on the validation of AgriPoliS, we can nevertheless find some instances with regard to which AgriPoliS may be considered a valid representation of reality. First, the model by Balmann (1997) which served as the starting point for AgriPoliS provided some explanations for real-world phenomena such as path dependence of structural change. As AgriPoliS preserves the general structure of Balmann's model, the validity of the original model is kept. Pyka and Fagiolo (2005) call this the "Take A Previous model and Add Something" (TAPAS) approach to empirical validation. Second, agent-based modeling allows us to consider key components of agricultural structures in a one to one manner. Third, we based the model's virtual farming structure on empirical data. As a result, the model reacts in ways similar to what we could observe in reality. We understand this in a way that we are able to reproduce some stylized facts of reality rather than an exact representation in a statistical sense. Finally, discussions with policy makers at the level of the federal state and the EU level as well as with practitioners showed that stylized nevertheless served as a good starting point for discussions on agricultural policy issues.

Fig. 8. Evolution of average rent and profit over 14 simulation periods and two policies, i.e., Agenda 2000 and the decoupled policy (REGPREM) for low factor levels (-), default, and high factor levels (+). Averages of five replications and standard errors. IBC stands for interest on borrowed capital, IEC stands for interest on equity capital, MA stands for cost savings due to managerial ability, and TC stands for technological change.



As much as similarity between the model and reality is desirable, the modeler needs to be able to communicate the model and its assumptions, limitations and results openly to an audience consisting of colleagues, knowledgeable experts, students, and policy makers. Here we are faced with the trade-off between the descriptive accuracy of the model and its explanatory capabilities. In view of policy-makers' requirements for good, precise, and valid models (Bonnen and Schweickhardt 1998, Bascou et al., *unpublished manuscript*), further extensions of our approach may be desirable; particularly because of the policy-makers' interests in complex interactions between economic, social, and environmental systems in rural areas. Based on these demands, directions for future research, and developments with AgriPoliS particularly concern the differentiation of heterogeneous agent behavior, demographic characteristics of farms, and a true coupling of AgriPoliS with GIS. The demand for model extension, may, however, increase model complexity significantly. To deal with this demand in a structured way, we advocate the use of methods such as DOE and meta-modeling, which help to explore a model systematically. Furthermore, direct involvement of policy makers in the modeling and analysis process may provide a way to meet policy-makers' demands. In this way, by picking a policy option out of the ensemble of alternatives which the simulations provide (Bankes 2002) policy makers would have the opportunity to exploit quantitative and qualitative knowledge that is not incorporated in the model.

Responses to this article can be read online at:
http://www.ecologyandsociety.org/vol11/iss1/art49/responses/

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