MODELLING STRUCTURAL CHANGE IN THE AGRICULTURAL SECTOR – AN AGENT-BASED APPROACH USING FADN DATA FROM INDIVIDUAL FARMS

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Abstract

The development of multi-agent models for agriculture has allowed the inclusion of farm decision-making behaviour and interactions in the simulation of smaller agricultural regions. Important methodological impact for this has come in particular from scientists from Germany. Currently under construction, the SWISSland model claims to depict as realistically as possible the 50,000 family farms comprising the whole of Swiss agriculture in all their heterogeneity as regards farm and cost structures as well as farm decision behaviours, with the aim of improving the simulation and forecasting of structural change. This paper describes methodological aspects in the formation of the agent population by combining various data sources such as accounting and spatial data and the results of surveys. As its basis, SWISSland uses the 3300 Swiss Farm Accountancy Data Network (FADN) farms, whose representativeness is substantially improved by means of a corrective procedure. Individual-farm optimisation models simulate the heterogeneous behaviour of the agents, for whom a potential exists for land trade within regional groups. With the linking of different methods and recorded data, we can expect to see a marked increase in the quality of the assessment of policy consequences.

Keywords

Structural change, Swiss agriculture, multi-agent model, agent definition, linear optimization.

1. Introduction

A certain change in paradigm seems to be taking place in agricultural sector modelling. Only a few of the leading research teams are still working on the development of sector models in which regional farms are optimised, as is, for instance, the case with CAPRI, RAUMIS and SILAS (Britz et al., 1999). By contrast, ever more teams are working on models in which several agents are optimised individually (Offermann et al., 2005), and also increasingly frequently in interaction with one another (Happe et al., 2008).

Matthews et al. (2007, p. 1447) summarise the advantages of agent-based models as follows: "Specific advantages of agent-based models include their ability to model individual decision-making entities and their interactions, to incorporate social processes and non-monetary influences on decision-making, and to dynamically link social and environmental processes." Expressed here is the concept that potential advantages of this instrument are wasted by persevering strictly in economic science, without borrowing from other disciplines.

This paper is intended to provide suggestions for possible data sources, definition methods and optimisation processes for agent populations, and thereby help to gauge the potentials of agent-based models for the agricultural sector. This occurs first and foremost using the example of the SWISSland model ('SWISSland' being the German acronym for 'Swiss Agriculture Structural Change Information System'), which is currently under construction. The aim of SWISSland is to gauge the effects of agricultural-policy decisions on the profitability and structure of Swiss agriculture as a whole, but at the same time also in a differentiated fashion for smaller regional areas; for the specific regional and local conditions are often decisive for the implications of policy measures on agricultural land use.

In Chapter 2, several previous approaches to the construction of agent-based agricultural structural models are described. Chapter 3 explains the definition of the agent population in the SWISSland model. Lastly, Chapter 4 shines a light on the conclusions for future model development.

2. Overview of the Literature for Deriving Agent Populations

Agent-based models consist of decision-makers (agents), an environment through which the agents interact with one another, and rules defining on the one hand the relationships between the agents and on the other hand the relationships between agents and their surroundings, as well as rules stipulating the sequence of the actions being performed in the model (Parker et al., 2002). In agricultural-economics agent-based models, the farm is frequently modelled as a decision-making unit. In this way, advantages can be used in data acquisition, in the illustration of path dependencies, behavioural heterogeneities and agent relationships, or in the communication of the model results via policy decision-makers or agricultural advisory organisations. Previous approaches used various methods for defining agents and generating the agent population (Tab.1). These are discussed below, in order then to develop an approach that is suitable for SWISSland.

TABLE 1: Structure of the agent population in existing agent-based models

Sample Model	ALBISSER (2008); LAUBER (2006)	BALMANN (2000); HAPPE (2004)	BERGER (2001); SCHREINEMACHERS (2006)	VALBUENA et al. (2008)
Data Basis	**Total population** Structured interviews with all farms: Survey of structural, economic and spatial features as well as behaviours (e.g. planned farm development)	**Sample** FADN data, planning data, expert knowledge for deriving the typical production technology	**Sample** Data from a household survey, planning data, qualitative information from field observations	**Sample** FADN data, planning data, survey and spatial data
Agent Population	**Total population** Agents = real farms	**Total population** Clones of typical farms	**Total population** Multiplication of the reference farms by means of the Monte Carlo Simulation	**Sample** Agents = sample (selection of typical agents)

Those approaches modelling all existing farms occurring in a region as agent populations are usually based on complex surveys for defining the socio-economic features and behavioural parameters of the model agents. The agents generally possess an explicit spatial reference, with the spatial location of each area being recorded by means of coordinates. Actually existing farms are thus modelled as agents in all their diversity. Owing to the high degree of effort associated with data collection, however, it is usually only small regions with few agents that can be included. Lauber (2006) and Albisser (2008), for example, have described Swiss communities with 72 and 30 existing farms, respectively; but the results of such case studies can only be generalised to a limited extent.

The concept of the definition of typical farms (Balmann, 2000; Happe, 2004) generally employs a small selected sample of FADN farms as a data basis for the agents. This selection is based on the regional characteristics (e.g. frequent production activities). Through identical multiplication ('cloning') of the farms – as a function of their occurrence in the population – an agent population is generated which corresponds to the actual size of the region. An economically rational behaviour is imputed to the agents based on the maximisation of profit. Heterogeneous attitudes and behavioural intentions are not taken into account in the initial versions of the model; the cost functons based on planning data are simply modified by means of randomly assigned correction coefficients for different management skills. In order to establish the spatial reference, the authors have divided the space to be modelled into grid cells.

These constitute usage units, and are assigned to the agents without reference to the situation in the concrete region. This approach simplifies the treatment, but does not take into account the varied shapes, sizes and ownership structures of the units of area. The method chosen by Balmann (2000) and Happe (2004) for producing an agent population by means of cloning reduces data and time overheads vis-à-vis the interview-based agent definition and enables the modelling of agent populations for relatively large regions with up to 3000 farms. This approach can only capture the actual heterogeneity of the individual farms to a limited extent, however, which is why sophisticated methods for defining agents and generating the agent population have been developed over the last few years.

The approach carried out by Berger (2001) and Schreinemachers (2006) uses so-called reference farms forming a representative sample of all the farms of a region to define the agents. In this way, the range of the farm characteristics to be taken into account can be substantially broadened. Based on the reference farms, a Monte Carlo simulation produces further model agents corresponding to the number of farms in the total population. The aim of this approach, however, is to avoid 'clones' in the population. The underlying data is based first and foremost on an extensive household survey (Berger and Schreinemachers, 2006). This is the starting point for econometric estimates of production and consumption functions as well as for deriving behavioural differences in connection with crop-rotation conditions, gender-specific division of labour or input and output prices. With this approach, regions with up to 3000 actually existing farms can also be modelled. The economic parameters of the agents derive for the most part directly from the reference farms, and display a high degree of individual-farm heterogeneity.

Valbuena et al. (2008) adopt a different approach. Rather than modelling the total number of farms in a region, the authors work with a selecton of typical agents. Their aim is to solve the dilemma between the great variety of characteristics of the agents and the often incomplete datasets. In comparison to the work of Balmann and Happe, however, more information on features such as intentions, perceptions, attitudes and the decision-making behaviour of the actors is used here. Different data sources of the most varied scales are combined with one another, for instance surveys of accounting data, farm census data, interviews, observations and GIS data. Special importance is placed on as realistic a depiction of the spatial distribution of the agent types as possible.

3. DEFINITION OF THE AGENTS IN SWISSLAND

As in most agent-based models in the agricultural sector, in SWISSland an existing farm is selected as an agent. The agent's strategic decisions with respect to farm growth, taking up a sideline or cessation of production are meant to agree with the decision making in Swiss farms. Since SWISSland is meant to represent the whole of Swiss agriculture, the agent population must reflect the heterogeneous structural and socio-economic characteristics and behaviours as realistically as possible. This applies in particular to the following features:

- Production facilities (land, buildings, labour)
- Type and extent of farming sectors
- Cost functions
- Plot structure (Arrangement in space, slope, travel distances)
- Investment behaviour
- Decision-making behaviour with respect to farm exit and transfer
- Decision-making behaviour with respect to switch to organic farming.

In addition to possessing the requisite realism, the agent population in the model must be sufficiently large and representative to enable policy statements to be made for the entire agricultural sector via extrapolation.

3.1 SUITABLE DATA SOURCES

The number of agents in SWISSland is based on the approximately 3300 reference farms of the Swiss Farm Accountancy Data Network (FADN) data pool. These farms form a non-representative sample of the approx. 50 000 family farms1 in Switzerland. A wide range of further data sources is available for defining the factor endowments, economic parameters and behaviours of the agents (Tab. 2).

The location, farm type, resource endowment and cost structure of an agent are based on the FADN data. However, the production type-specific datasets (crop yields, direct costs, prices) are not sufficient to determine the cost functions for each production line of an individual farm. For this, further data on working time and machinery costs and feed input, which are only available for the FADN farm as a whole, are required. Nevertheless, allocation of the

[1] Not illustrated are around 10 000 micro-farms and farms with special ownership structures (e.g. farming collectives, state-owned farms). These account for around 5% of the utilised agricultural area in Switzerland (Meier, 2005) and exert no more than a slight influence on the structural development of family farms.

data according to defined allocation criteria as described in Mack and Mann (2008) enables the calculation of cost functions for each production line on the basis of the accounting data for all 3300 agents.

FADN only contains monetary data on the equipping of farm buildings. Further data on the building stock can be estimated by means of surveys, at least for dairy farms (Gazzarin et al., 2008). These surveys reveal that over the past few years, many dairy farms have invested in new building units, which are nonetheless not fully utilised, owing to a lack of both space and milk quotas.

TABLE 2: Definition of the model agents and data sources

Features of the Agent	**Data Sources**
Location, farm type, resource endowment, cost functions of the production liness	Individual-farm accounting data (Swiss FADN)
Buildings: Type, size, age, utilisation	Representative survey of 407 Eastern Swiss dairy farms (GAZZARIN et al., 2008)
Spatial farm structure	Spatial data of farms from around 10 sample communities
Farm exit or farm succession	Representative survey of 776 exiting farmers (ROSSIER and WYSS, 2006)
Risc behaviour of an entering agent (keen on, neutral towards, or averse to growth)	Representative survey of 1023 young new-entrant farmers (ROSSIER, 2008)
Attitude towards organic farming	Representative survey of approx. 500 organic and approx. 500 non-organic farms (REISSIG et al., 2009)

Since the land market is an important part of the interactions between the agents in the SWISSland model, spatial features must be specified for all agents. These go beyond the simplified assumption of grid formation characterising many models; rather, SWISSland is meant to model the spatial topology of the farm centres and plots required for the simulation of the land market. No spatial coordinates and no spatial-structure data (number of plots, distances between farms and plots, number of neighbours) exist for the 3300 agents, however. The location and the cultivation of the individual acreages is therefore unknown. In order to estimate and allocate these features, individual reference communities with 70 – 100 farms each are selected as representative of regional types with similar structural and topographic characteristics. In these reference communities, spatial data is collected by means of GIS databases and detailed surveys on the agricultural use of the land, in order to then apply said data to the model agents.

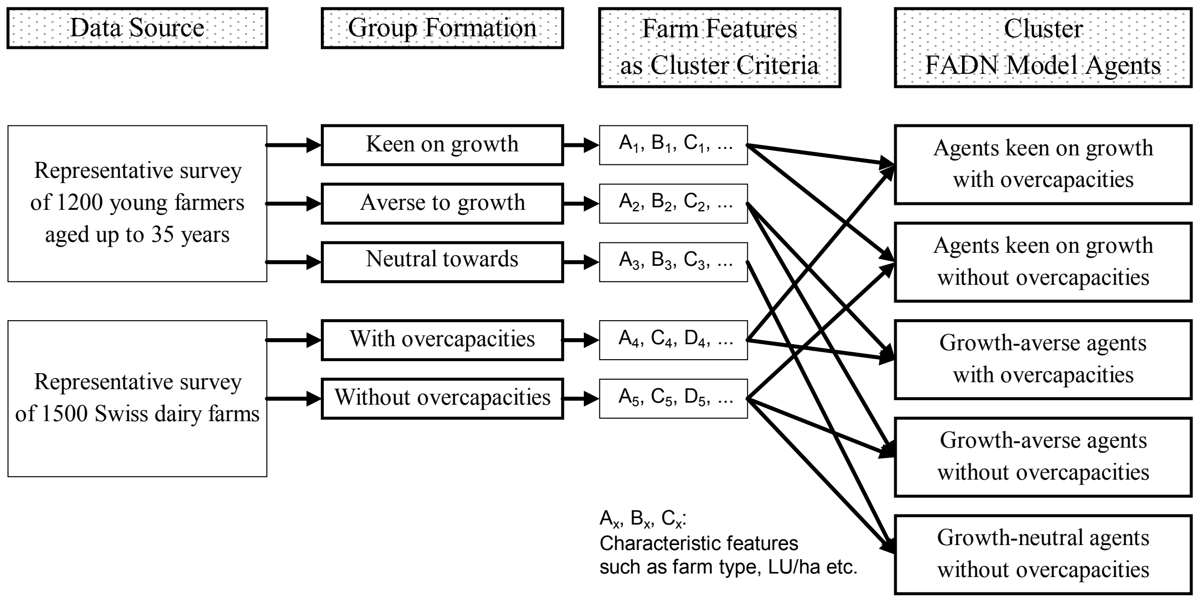
Various surveys can be used to depict the heterogeneous behaviours with respect to farm development (Rossier and Wyss 2006, Rossier 2008, Reissig et al. 2009). Based on these data, the investment and disinvestment behaviour of agents entering, exiting and 'staying put' in farming is specified.

3.2 Suitable aggregation of various data sources into an agent

The features from the various data sources and survey results as well as the spatial data must be allocated to the 3300 agents in such a way that the agent population thus generated behave like real farms. Figure 1 shows the SWISSland approach for allocating data from different, non-overlapping samples to an agent.

In order to apply the survey results to the FADN farms, for example, the farms taking part in the survey are initially grouped according to the relevant distinguishing criteria and investment behaviour. For these groups, characteristic features such as farm type, utilised agricultural area, arable and non arable land, livestock production are determined. Using cluster analysis, the FADN farm agents exhibiting the same combination of features are then determined. The other additional data, particularly the spatially explicit features, are allocated to the model agents via the same method.

FIGURE 1: Aggregation of various data sources into an agent



3.3 Suitable Method for Improving the Representativeness of the Agent Population

Since the 3300 FADN farms constitute an insufficiently representative sample of Swiss farms, it is to be expected that the extrapolation of farm data will lead to significant deviations from the whole-of-Switzerland features. With extrapolation methods that assign different weightings to the individual farms, the quality of fit could be improved. However, this would lead to inconsistencies with respect to the modelled relationships between the farms: a land deal between farms to which differing extrapolation factors are assigned would yield a change in the overall modelled area. It is therefore advisable to improve representativeness before the model applications by adjusting the sample.

Similarly to the region initialisation in Happe (2004), a weighting of the FADN farms takes place. In an optimisation calculation, each farm is assigned a weighting factor of zero, one, or greater than one. This determination of the farms to be deleted or multiplied pursues the aim of even better adaptation of certain features in the extrapolation to the whole-of-Switzerland values. The optimisation calculation minimises the sum of the squared deviations between the extrapolated features of the farms and the extent of these features in the basic population.

Minimisation:

$$\sum_f \left(\sum_n \frac{w_n * F_{fn} * E}{S_f} - 1\right)^2 * W_f \rightarrow \min$$

Sum of the squared deviations

where:

wn: Sought-after weighting of FADN farm n (Integer-variable, standard value: 1)

Ffn: Extent of feature f on FADN farm n

E: Extrapolation factor between the SWISSland agent population and the farms throughout Switzerland

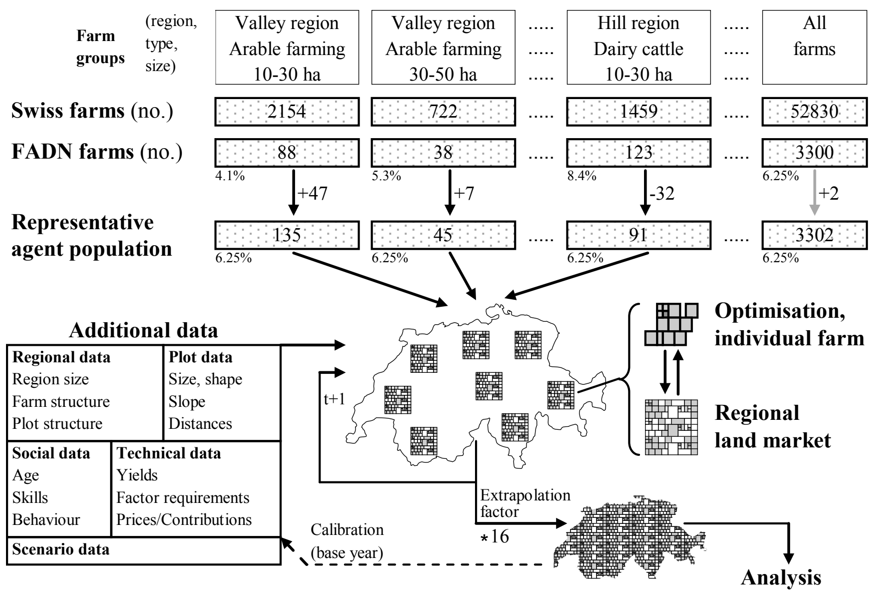
Sf: Optimum mapped extent of the feature f in Swiss agriculture

Wf: Feature-weighting factor of feature f (relative weighting of the features observed)

The list of the features to which this adjustment of the agent population is geared contains e.g. the sizes of particular land and animal categories or the number of farms of a certain form (sideline, tenancy, organic, regional location). Here, of course, the definition of a feature on the farm level must agree with the definition on the sectoral level. The features can be weighted among one another (factor Wf). A constraint ensures that the sought-after weighting factors of the farm (wn) do not become negative. With additional constraints, the features within a particular range can be required to end up at around the actually observed size. Moreover, in order that the original FADN farm sample be altered as little as possible, the maximum number of farms to be deleted (weight wn = 0) can be given. In the optimisation calculation, additional binary variables per farm (if wn = 0 → 0; if wn > 0 → 1) are formulated for this purpose. In the SWISSland model, interactions between the farms for the time being only take place within defined market regions. It would therefore be possible to stipulate different extrapolation factors for these market regions, or even to offer various extrapolation factors per region from which the most suitable one in each case is selected at the same time as the farm weighting factors are determined. To do this, the variables wn would also have to be differentiated according to potential market region affiliations. In this way, the farms would be allocated to the market regions at the same time as the optimisation calculation was made.

A further possible variant in the determination of farm weighting factors for improving the representativeness of the agent population is outlined in Figure 2.

FIGURE 2: Adjustment of the agent population (no. of farms) and model sequence



In the Swiss FADN publications, grouping of the farms according to the features 'region', 'farm type' and 'size category' has proved suitable for weighting the results according to the representation of these groups (Meier 2005). By means of the analogous grouping of the farms throughout Switzerland (AGIS Database: FOAG 2008) and applying a given extrapolation factor, the required number of agents per group can be calculated, and with it the number of FADN farms missing or surplus in each group. During the ensuing optimisation calculation for determining the farm weighting factor wn, additional constraints are applied to ensure that per group, farms are only ever either omitted or multiplied, with the result that the original FADN-farm sample is altered as little as possible. The agent population corrected in this manner corresponds to a percentage of real Swiss farms stipulated according to the extrapolation factor. Allocation to the market regions could be through the grouping of farms which in reality are close to one another into the characteristic group sizes. After the allocation of additional data not recorded in the FADN, such as the different behaviours, the agent population is defined and ready for model calculations. The results of such model simulations can in each case simply be extrapolated by means of the extrapolation factor to the whole of Switzerland, or to certain subregions.

3.4 Suitable Optimisation of the Agents

The agents of the SWISSland model are formulated as a mathematical optimisation model and calibrated with the aid of the Positive Mathematical Programming (PMP) approach. The model provides for a series of farm action options (decision-making variables or activities) as well as restrictions. Since the investment decisions can only assume integer values, we are also dealing here with a mixed-integer model. In a first step, it is assumed for the SWISSland model that the individual-farm activities of a given period can be derived from the maximisation of the expected household income, bearing in mind technical and financial restrictions such as available area, work equipment, financing options, or conditions for receiving direct payments. Heterogeneous behavioural attitudes such as the intention of farm growth are modelled via adaptations of the coefficients and capacity parameters, or via flexibility constraints. The chart used by the agents is illustrated by way of example in Figure 3, whilst the most important variables are described in Table 3.

FIGURE 3: Overview of the optimisation model

		Investment	Financing	Plant production	Animal husbandry	Permanent crops	Grassland	Utilisation	Sideline	RHS
		i	c	c	c	c	c	c	c	
	Household income	Objective-function coefficients								Max.
Factor Capacities	Liquidity (CHF)	Technical coefficients								Capacities
	Minimum equity reserves (CHF)									
	Land use (ha)									
	Area devoted to roughage (ha)									
	Animal husbandry (places)									
	Labour (MPh)									
Ecological Rstric-tions	Manuring (kg N/ha)									
	Nutrient balance (kg N, P, K)									
	Rotation (% of UAA)									
	Ecological compensation area (% of UAA)									
Other	Flexibility constraints (% of previous year)									

Note: c = continuous activities, i = integer activities

TABLE 3: Important variables in SWISSland

Variable	Unit	Type	Description
Investment	various	Integer	Investment alternatives for new investment in buildings and systems for agents keen on growth
Financing	CHF	≥ 0	Investment assistance, contributions and other outside capital
Plant production	ha	≥ 0	Plant-production method
Animal hus-bandry	various	≥ 0	Animal-husbandry method
Permanent crops	ha	≥ 0	Permanent-crop cultivation method
Grassland	ha	≥ 0	Use of meadows and pastures
Utilisation	various	≥ 0	Factor- and resource utilisation
Part-time occu-pantion	MPh	≥ 0	Working hours for non-agricultural occupation
Household in-come	CHF	Free	Agricultural income plus non-agricultural in-come

Household income is yielded from the sum of agricultural and non-agricultural income. It must compensate the work contributed by the farm managers and the equity-capital invested. The quadratic objective function encompasses the following components:

$$Max\ Z_t = \sum_i p_{it}y_{it} + \sum_j dz_{jt}x_{jt} + \sum_g al_{gt}fak_{gt} - \sum_g l_{gt}ak_{gt} - \sum_k v_{kt}u_{kt} - \sum_k v_{kt-1}u_{kt-1} - \sum_r s_{rt}h_{rt}$$
$$- \sum_j \alpha_{jt}x_{jt} - 0.5\sum_j \beta_{jt}x_{jt}^2$$
$$\text{s.t.}\ \ \mathrm{m}_n\left(x_{t=1,j=1},\ldots,X_{t=T,j=J}\right) \le 0$$

where:

Z =	Objective-function value (household income)
p =	'Expected product prices' vector
y =	'Sales and purchase activities' vector
dz =	'Direct payments' vector
x =	'Plant and animal production activities' vector
v =	'Expected prices of investments' vector
u =	'Investment activities' vector (stalls)
al =	'Non-agriculturally achievable wages' vector
fak =	'Family labour units' vector
l =	'Wages' vector (for family and non-family labour units)
ak =	'Labour units' vector (family and non-family labour units)
s =	'Expected prices for miscellaneous inputs' vector
h =	'Miscellaneous inputs' purchase activities' vector
mn =	Restrictions of all decision variables with n different equations
α =	Vector with parameters of the linear term (PMP)
β =	Matrix with parameters of the quadratic term (PMP)
j =	{1,..., J} (Set of production activities)
i =	{1,..., I} (Set of purchase and sales activities)
k =	{1,..., K} (Set of investment activities)
r =	{1,..., R} (Set of utilisation of resources, e.g. energy, water, nutrients, feed, etc.)
g =	{1,..., G} (Set of work activities)
t =	{1,..., T} (Set of time periods – years)
t-1 =	Previous year

The time frame of a simulation round is one year. The recursive model approach enables the analysis of developments over the course of time, in that several simulation rounds are carried out one after the other. The result of one year is the basis for the following year. Farms can exit production owing to illiquidity or inadequate coverage of opportunity costs.

The Positive Mathematical Programming (PMP) approach enables the model to be calibrated on a statistically proven initial position (base year). This means that the forecast calculations are more realistic and plausible, and are less prone to overspecialisation than pure LP solutions. It is, however, disadvantageous that the quadratic cost function only represents an assumption which is empirically difficult to validate.

The large number of heterogeneous agents requires a minimum number of different activities in plant and livestock production. Outside labour units may be hired in the model. Where capacity is freed up, for example through an investment, family labour units can also take advantage of non-agricultural employment opportunities, so long as it can be assumed that these are available and a minimum number of working hours are put in on the farm.

Alternatives for new investment in buildings and systems are modelled in a similar form to that proposed by Happe (2004, p. 45 ff.) or Kellermann et al. (2007, p. 23 ff.). Here, potential investment alternatives for the various activities are offered, with various sizes of an investment type being taken into account in order to illustrate scale effects. In addition, the assumption of myopic decision-making behaviour applies.

The necessary capital for production and investments is available in three forms: short-term outside capital, medium- and long-term outside capital, and liquid equity. Mortgages and investment assistance (non-repayable contributions) as well as investment loans are part of the medium- and long-term outside capital which, in addition to own resources, is available for investments. Investment assistance and loans can only be used if previous investment loans have been repaid in full. In order to receive investment assistance and loans there must be compliance with legal framework conditions, which must be implemented accordingly in the model. In addition, there is a restriction on usable equity for investments, so as not to jeopardise the farm's capital. Furthermore, flexibility constraints are integrated which ensure that all capacities available from the previous years are fully utilised. This means that all plant (as well as animal) production activities can go back to the maximum extent within the framework of the reciprocal building depreciation rates.

4. Conclusions

The larger the agent population to be modelled in an agent model, the less detailed the design of the individual-farm optimisation models or agents generally is. SWISSland aims to model both a large agent population and the individual agent as realistically as necessary, for which complex individual-farm optimisation models are, however, essential. This entails several difficulties. Besides technical capacity problems, a high degree of detail harbours the risk of problems with model validation and the interpretation of the model results. Communication with policy decision-makers becomes more difficult if the modelled connections are not sufficiently comprehensible (cf. Happe and Kellermann, 2007). Finding a reasonable balance between complexity and simplification will therefore be a criterion of success in the modelling of SWISSland.

Here, the fact that not only a manageably sized region but an entire country is to be modelled is of importance. Although Switzerland, as is known, is one of the smaller nations, the goal of a national model standard demands the processing of potentially extremely large quantities of data. This reinforces the pressure to abstract in certain places, without unnecessarily restricting the wealth of single-farm individuality.

All in all, it appears that multi-agent models are in fact in a considerably better position to model complex reality than old-style aggregated sector models. Through the deliberate use of suitable selected documents and with the assistance of different disciplines, modelling can home in on the mechanisms, and above all the heterogeneity, of human behaviour. In this way, we continue to bear in mind the aim of realistically appraising policy consequences.

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