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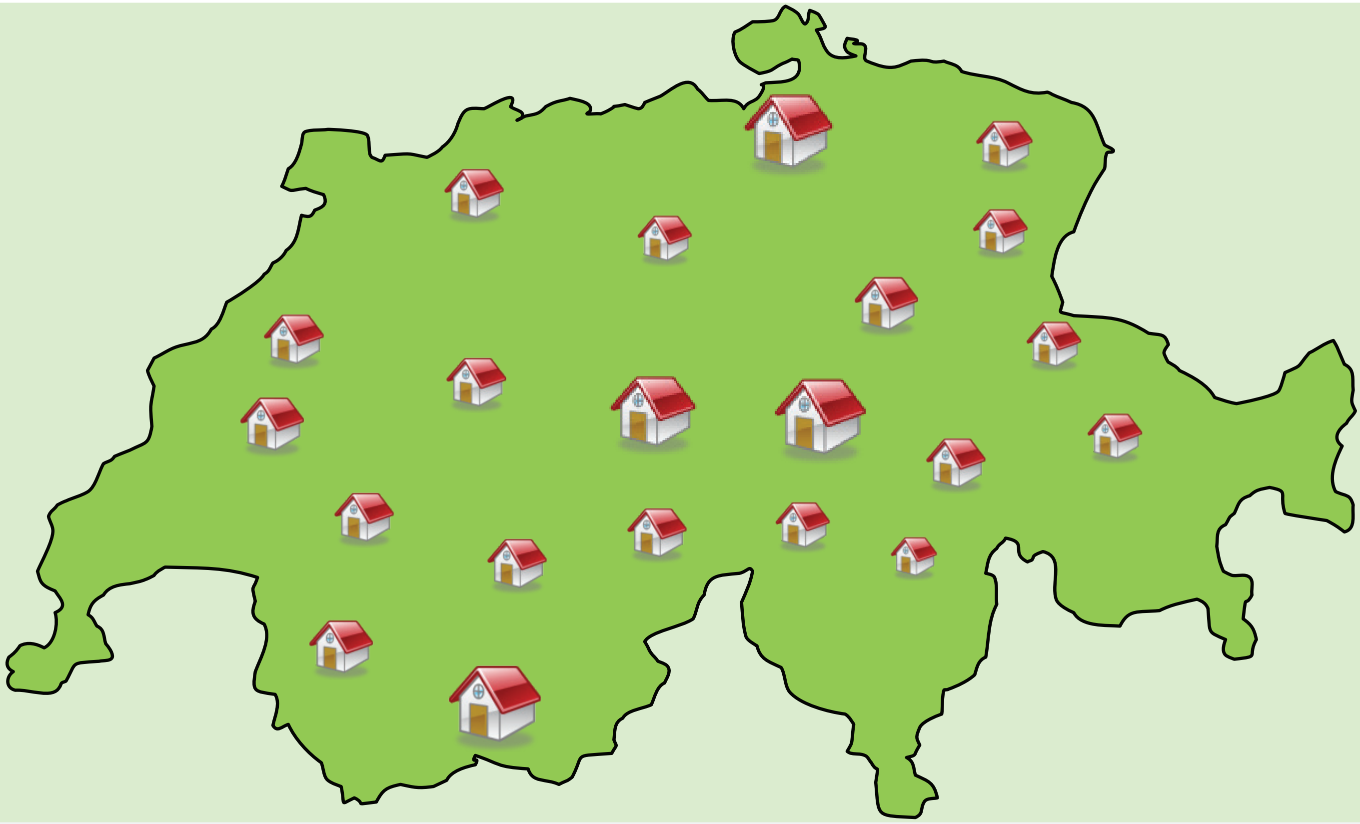

Agent-Based Modeling on a National Scale – Experiences from SWISSland

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Zusammenfassung

SWISSland ist das erste agentenbasierte Modell, das Aussagen über den Sektor eines ganzen Staates macht. Seit 2008 mit dem Aufbau des Modells begonnen wurde, ist in seine einzelnen Module zwar eine unglaubliche Menge von intellektueller Energie und Zeit hineingeflossen; es wurde bislang aber nie der Versuch unternommen, das gesamte Modell auf eine nicht-technische Weise zu dokumentieren.

Der traditionelle Schwerpunkt von Agroscope liegt auf der produktionsorientierten Agrarforschung. Entsprechend liegt auch im SWISSland-Modell ein Schwerpunkt beim Angebotsmodul, in dem über 3000 in «Gemeinden» strukturierte Betriebe miteinander Flächen tauschen und jährlich ihr Produktionsverhalten auf die Rahmenbedingungen wie Preise und Direktzahlungen ausrichten. Auf der Grundlage dieser Betriebe wird im Anschluss an den Optimierungsprozess eine relativ komplexe Hochrechnung auf den gesamten Sektor der Schweiz durchgeführt. Gleichzeitig gibt es im Modell aber auch ein Nachfragemodul, das auf der Grundlage von Marktdaten möglichst plausible Prognosen für Handelsbilanzen und Inlandpreise erstellt. SWISSland nachgeschaltet gibt es schliesslich noch diverse Instrumente aus dem ökologischen Bereich, die für die unterschiedlichen Modellszenarien Aussagen über die Entwicklung umweltbezogener Parameter wie etwa der Stickstoffbilanz erlauben. Ausführungen zur technischen Anordnung von Daten und Modellrestriktionen, Einblicke in übliche Visualisierungsformen der Modellergebnisse sowie Beispiele zu Anwendungsfällen des Modells runden den Bericht zu SWISSland ab.

Summary

SWISSland is the first agent-based model that purports to make statements about the agricultural sector of an entire country. Although a phenomenal amount of intellectual energy and time has been invested in individual modules of this model since its setup in 2008, no attempt has previously been made to document the model as a whole in a non-technical manner.

Traditionally, Agroscope's emphasis has been on production-oriented agricultural research. Accordingly, the SWISSland model places part of its focus on the supply module, in which over 3000 model farms organised into "communities" exchange land with one another and optimise their portfolio annually in terms of prices and direct payments. On the basis of these farms, and after the optimisation process has taken place, a relatively complex extrapolation to Switzerland's entire sector is performed. At the same time, however, SWISSland also includes a demand module that uses market data to create forecasts of maximum plausibility for trade balances and domestic prices. Lastly, there are a number of agro-environmental tools located downstream of SWISSland that allow us to make statements on the development of environmental parameters such as nitrogen balance for the different model scenarios. Remarks on the technical design of data and model restrictions, insights into common visualisation options for the model results, and examples of applications of the model round out this report on SWISSland.

Résumé

SWISSland est le premier modèle multi-agents qui permet de se prononcer sur le secteur agricole de l'ensemble d'un pays. Depuis 2008, date à laquelle la conception du modèle a débuté, une quantité incroyable d'énergie intellectuelle et de temps a été investie dans les différents modules, mais aucune tentative n'avait encore été faite pour documenter l'ensemble du modèle de manière non technique.

Traditionnellement, Agroscope donne la priorité à la recherche agronomique orientée sur la production. Par conséquent, le modèle SWISSland fait lui aussi du module de l'offre un de ses points forts. Dans ce module, plus de 3000 exploitations structurées en «communes» échangent des surfaces et adaptent chaque année leur production en fonction des conditions-cadre, comme les prix et les paiements directs. A partir de ces exploitations et à la suite du processus d'optimisation, une extrapolation relativement complexe permet de transposer les résultats à l'ensemble du secteur agricole suisse. Le modèle comprend également un module de demande qui repose sur les données du marché et établit les pronostics les plus plausibles en matière de bilans commerciaux et de prix intérieurs. En aval de SWISSland, il existe enfin divers instruments dans le domaine écologique qui permettent, en fonction de différents scénarios, de tirer des conclusions sur l'évolution de paramètres liés à l'environnement, comme le bilan de l'azote. Des explications sur l'agencement technique des données et les restrictions du modèle, un aperçu des options de visualisation des résultats ainsi que des exemples d'application du modèle complètent ce rapport sur SWISSland.

List of Abbreviations

AGIS	Agricultural Policy Information System
AGLINK / AGLINK-COSIMO	Recursive-dynamic, partial equilibrium, supply demand model of world agriculture
AGRIPOLIS	Agricultural Policy Simulator
ALU	Annual Labour Unit (1 ALU = 2800 hours per year)
AP 14-17	Agricultural Policy Reform 2014 bis 2017
BN	Bayesian Network
CAPRI	Common Agricultural Policy Regionalised Impact Modelling System
CPLEX	High-performance mathematical programming solver for linear programming, mixed integer programming, and quadratic programming
DB	Database
DG Agri	Directorate-General for Agriculture and Rural Development of the European Commission
EAA	Economic Accounts for Agriculture
EPIC	Environmental Policy Integrated Climate Model
ESIM	European Simulation Model
EU	European Union
FADN	Farm Accountancy Data Network
FAPRI	Agricultural Model of the Food and Agricultural Policy Research Institute with centers at Iowa State University, Ames, and the University of Missouri, Columbia
FAPSIM	Food and Agricultural Policy Simulator
FARMIS	Comparative-static Programming Model for farm groups
FOAG	Swiss federal Office for Agriculture
FOEN	Federal Office for the Environment
GAMS	General Algebraic Modelling System
GDP	Gross Domestic Product
GIS	Geographical Information System
GTAP	Global Trade Analysis Project
ISO	International Organization for Standardization
ISS	Institute for Sustainability Sciences ISS
LCA	Life-cycle Assessment

LMM	Land-Management Model
LU	Livestock Unit
m.a.s.l.	metres above sea level
MCP	Mixed Complementarity Problem
MySQL	Database Software
OECD	Organisation for Economic Co-operation and Development
PMP	Positive Mathematical Programming
RCLU	Roughage Consuming Livestock Unit
Repast	Java-based modelling system
RHS	Right Hand Side
SAO	Swiss Agricultural Outlook
SBV	Swiss Farmers Union
SECO	Swiss State Secretariat for Economic Affairs
SFSO	Swiss Federal Statistical Office
SILAS	Swiss Information System for agriculture (agricultural sector model)
SLU	Standardised Labour Unit
SNB	Swiss National Bank
SWD	Standardised Working Day
SWISSland	Information system of structural change in Switzerland / StrukturWandel InformationsSystem Schweiz (www.swissland.org)
TEP	Animal husbandry under difficult production conditions
TRQ	Tariff Rate Quota
UAA	Utilised Agricultural Area

1 The Advantages of Agent-based Models as Motivators for SWISSland

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1.1 SILAS as an example of traditional sector models: strengths and shortcomings

Against the backdrop of major progress in hardware computer technologies during the fourth quarter of the 20th century, the 1990s became the decade of agricultural sector models. At first, the American FAPRI model had a preemptive advantage (Devadoss *et al.*, 1993); then the Germans designed CAPRI (Henrichsmeyer *et al.*, 1997) to depict European agriculture, the Americans focused on GTAP (Hertel, 1997), and a European-US alliance developed the European Simulation Model ESIM (Josling *et al.*, 1998).

Many policy-makers realised that model results could strengthen their arguments so that policy packages became easier to sell and the effects of new instruments could be anticipated more readily. This notion was also adopted by the Swiss Federal Administration, creating a demand for a Swiss agricultural sector model associated with the introduction of direct payments in Swiss agricultural policy. At this time, the Tänikon Research Station had a strong farm-level focus. Prior to the 1990's, the only Swiss agricultural research organisation with a more sectoral focus was ETH Zurich, where Peter Rieder lectured in agricultural policy and Awulu Abdulai taught demand analysis. A chronic structural problem at universities, however, has always been the element of change. Continuity in terms of staff is crucial, but difficult to achieve in an organisation focusing on education. In 1993, it was therefore decided that the construction of a forecasting agricultural sector model should be allocated to Tänikon rather than Zurich, to the new (small) "Forecasting Systems" research group led by Oliver Malitius.

Oliver Malitius developed good scientific and personal contacts with Bonn, where CAPRI was developed. It is therefore hardly surprising that the anatomy of the Swiss sector model SILAS was quite similar to that of the CAPRI model. Like CAPRI, SILAS treated regions as agents with an optimisation function. In the case of SILAS, Switzerland was divided into eight zones ranging from the lower valley area up to Mountain Zone IV. Each zone had its resource restrictions under which sector income was maximised, subject to shadow costs integrated through Positive Mathematical Programming.

When I joined the Tänikon Research Station in 2002, its Director Walter Meier described SILAS to me as a "cash cow". By that time, the model had become firmly established, and except for some model runs, little intellectual investment was required in order to generate results used in scientific publishing (Malitius *et al.*, 2000; Mack and Mann, 2008; Zimmermann *et al.*, 2011) and, even more importantly, in policy consulting. In its first few years, credibility problems arose from the fact that external prices produced by the Federal Administration were fed into the model; however, these problems were soon overcome by the introduction of a market model that could be linked to SILAS (Ferjani and Zimmermann, 2013).

In almost all forecasts made with SILAS, sectoral income fell over time. At the same time, common sense would lead us to anticipate structural change through the exit of a number of farms. The question of whether these two developments would add up to a decrease or increase in single-farm income was often asked, but could not be answered based on model results. In general, structural change was one of the core variables for understanding the dynamics of Swiss agriculture. Which developments would speed up structural change, and which would preserve the current texture of a large number of small farms?

This pragmatic issue was linked with a conceptual one. Swiss agricultural development is the result of a large number of decisions made by around 50 000 Swiss farmers or farm families. These decisions are in part driven by the desire to make money, in part by other factors. If the objective is to forecast the results of these decisions, doesn't the reduction of this complexity to an abstract profit-maximisation exercise in a small number of regions result in the loss of considerable information?

1.2 The range of agent-based models

SILAS's shortcomings as described above led to the resolve to continue the forecasting work on an agent-based model, as well as to a two-day workshop in Basel to which Katrin Happe, one of the leading brains behind AGRIPOLIS, was invited. AGRIPOLIS was the first major agent-based model for agriculture (Happe *et al.*, 2006), and thanks to both its logical structure and Katrin Happe's impressive input into the workshop, AGRIPOLIS was as much a role model for SWISSland as CAPRI was for SILAS.

Agent-based models are very much a 21st-century phenomenon. They have been applied in an extremely wide range of fields, from consumer behaviour (Delre *et al.*, 2007) to travel forecasting (Raney *et al.*, 2003). The outbreak (Carley *et al.*, 2006) and control (Segovia-Juarez *et al.*, 2004) of diseases is another prominent field in which agent-based modelling is applied.

Determining different land-use options is probably the main purpose for which agent-based models have been developed, however. The acting agent seems to be the most convenient starting point for explaining or predicting choices between different options for deriving utility from land. Whether residents cause urban sprawl (Brown and Robinson, 2006), whether they compete with farmers in their claims on land (Parker and Meretsky, 2004), whether land can be used for forest or for farming (Evans and Kelley, 2004), or whether it is only several farming options that are available (Castella *et al.*, 2005) – optimising agents seems to be a promising method for the anticipation of plausible future developments.

1.3 What agent-based models can and cannot do

Land is a clearly measurable resource which can be converted into financial gain or loss through a limited number of uses. Land-use models dominate the landscape of agent-based models, pointing to the conditions in which this model category functions successfully. Their relationship with economic impacts, however, is only the reason why optimisation models in general have been so popular over the last 25 years for explaining land-use changes.

The appeal of agent-based models lies in a different realm. It must originate from the existence of the agent itself, the core part of this model group. Classical models also had their "agents", albeit only theoretical ones. They optimised a unit which will never be optimised in real life. The great achievement of agent-based models is their integration of the heterogeneity of individuals and transactions, accomplished by placing the optimisation process back on the unit where it actually occurs. This is not a new insight. It was put best by Garcia (2005; 383), who found that the greatest advantages of agent-based models were "when the population is heterogeneous or the topology of the interactions is heterogeneous and complex".

Farmers are an excellent case in point for such a heterogeneous but large population. Some farmers switch between organic and conventional farming, whilst others are strictly loyal to one approach (Mann and Gairing, 2012). They have different production objectives (Zingore *et al.*, 2007), as well as extremely divergent attitudes towards non-agricultural activities (McElwee and Bosworth, 2010). It is as challenging as it is promising to collect the distribution of these characteristics in a given population for some of these aspects, and to translate them into additional model restrictions.

Agent-based models only reach their potential if interaction between the agents is included as an option. In the case of land management, this option is of particular relevance in real life: Due to the different restrictions under which they operate, different land users have very different potentials for making profitable use of a plot of land. In such cases, it is likely (or at least possible) that land will be transferred from an unprofitable user to a profitable one. This is a dynamic that agent-based models are good at depicting.

All this is not only an intellectual challenge, but also a technical one. Given that they require a great deal of hardware capacity, it is no coincidence that agent-based models have become common only recently. Even now and with modern equipment, there have been times when a single SWISSland run has exceeded 24 hours. This is less a question of the optimisation of the 3000 farms in the model than of the interaction between competing neighbours after a farm is abandoned.

What are the greatest limitations to agent-based models? Precision is certainly an issue. From econometric analysis, we know that it is hardly ever possible to explain 100 per cent of human behaviour. For some issues, in fact, it is even difficult to explain 10 or 20 per cent. It is therefore scarcely reasonable to expect the ability to make predictions in every single case.

Experience shows, for example, that while it is possible to predict price fluctuations for certain items, it is impossible to predict just when short-term prices will go up or down. This is as impossible as predicting the behaviour of an individual agent, even if, at the end of the day, aggregated measures will do a good job of this.

2 The SWISSland Structure

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An agent-based model consists of decision makers (agents), an environment through which the agents interact with one another, and rules which define the relationships between the agents on the one hand and the relationships between agents and their environment on the other, as well as rules defining the sequence of the actions occurring in the model (Parker *et al.*, 2002).

Even at the start of the modelling work, we were aware that fundamental decisions had to be made beforehand, to allow us to cope with the greatest challenges in creating an agent model. Some results of this initial phase of the project are summarised below.

2.1 Purpose

SWISSland is a model system for illustrating and projecting supply-and-demand quantities at agricultural-sector level whilst taking account of (nett) external trade in agricultural goods on the global market. The SWISSland model fulfils the three main objectives depicted in Figure 2.1.

2.2 Who or what are the agents?

Agents in SWISSland are represented by actual farms in the model. These are exclusively family farms operating all year round whose total income is generated mainly on the farm. The model also includes agents farming exclusively in the mountain region at an altitude of over 1000m above sea level (alpine farms). Run during the summer grazing season only, they are legally either individual private-sector agricultural enterprises, or public partnerships.

The following main arguments (cf. also Schreinemachers, 2006; Berger, 2001; Odening and Balmann, 1997) speak for the advantages of such an approach:

- Policy decision-makers and agricultural advisory organisations would like to gauge the effect of agricultural policy measures at farm-household level. The individual farm possesses policy implications, since only decisions at individual-farm level determine the dynamism of the agricultural sector and are capable of influencing it accordingly.
- Data availability is essential for parameterising an empirically supported simulation model. The depiction of "individual farm" agents suggests itself, since many socioeconomic data sources exist for this organisational unit, thus enabling scaling problems to be minimised.
- Interactions between the agents, such as the exchange of resources e.g. in the form of the land market and the adoption of innovative technologies, generally take place at individual-farm level.
- In terms of decision-making behaviour, the agents act autonomously. This requirement can be assumed for the individual farm. The personal characteristics of the farm manager (age, education, etc.) and his or her business conduct also have individual-farm relevance.
- The adaptability of the agents is determined by the structural realities of the farm (factor endowment, soil quality, topographic and climatic conditions, opportunities for off-farm activity, opportunities for cooperation, market access, etc.). The farm level therefore represents a sufficiently high level of abstraction for depicting behavioural heterogeneity.

2.3 Challenges in design

A precise forecast requires a clear formulation of objectives, a reproducible data source that has been validated for

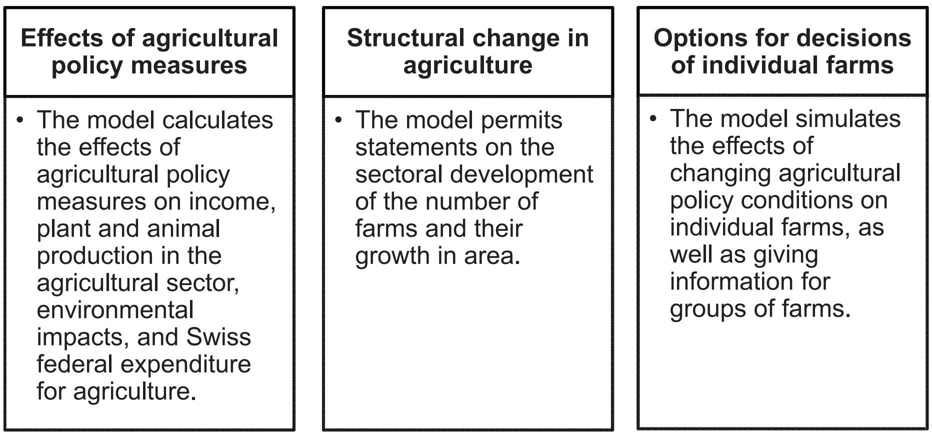

Figure 2.1: Objectives of the SWISSland agent-based agricultural sector model.

plausibility, the definition of the agent population and the delineation of its representativeness for the basic population, as well as a precise identification of the model-endogenous circumstances and processes to be illustrated.

It must be ensured that the available spatial data are scaled so as to be compatible with the spatial level on which the decision makers act, and on which further processes that are to be modelled take place.

The behaviour of the agents cannot be covered by a single theoretical concept of decision-making. Various concepts are to be tested as to their empirical validity, in order to determine which behavioural models are best suited, and in what form they can be implemented in the model.

To arrive at a regional, sectoral or otherwise-dimensioned agricultural structure level from the individual-farm results of the model, a process must be developed which does as good a job as possible of reflecting the reactions of the farm model on the one hand and the official agricultural statistics on the other. Accordingly, the representativeness of the available spatial data must be valid for the various output levels.

With complex simulation models, both model validation and model verification are very time-consuming processes. Advance planning of the individual validation steps is essential, and influences both model input and model output requirements.

Regarding the temporal dimension of the model approach, a decision must be made as to whether the focus of the policy analyses carried out with the aid of the model is to be the presentation of the developments over time, or whether the aim is to attempt to depict the situation at a specific start- and end point. The modelling method (recursive-dynamic vs. comparative-static) must be adapted accordingly.

Creating an agent model is very cost-intensive, and places high demands on computing resources. From the start, as flexible and long a use of the model as possible was deemed desirable. At the same time, there was the aim of increasing the efficiency and productivity of the material and human resources deployed. Thus, before the modelling was begun, there were a number of basic questions to answer in terms of computing needs and technical implementation (cf. also Chapter 6):

- Computing needs rise with the scope of the complexity to be illustrated. What software and hardware is suitable for best satisfying these needs?
- The core competencies of our Research Institute lie in the economic, technical and social depiction of the farm or the agricultural sector, but not in the field of computing. What core competencies are available internally in terms of modelling? What programming competencies can be outsourced? How can the risk of dependence on external service providers in an environment of decreasing financial resources be minimised?
- The model processes a very large volume of data. What database software is suitable, and how can the interfaces be designed so as to be compatible with the individual modules of the model? How can data exchange between the individual components of the model be organised in an efficient and time-saving manner?
- As data volume and model complexity increase, so also do the individual computing times of a model run. With model tests that are sometimes extensive, these model run times are a limiting factor. For this reason, we planned measures for shortening the model run times in advance. These include, for example:
  1. Modelling "from small to large" and vice versa,
  2. Modular construction (not all modules are always running),
  3. Starting from a saved dataset within the simulation run ("save and restart"),
  4. Optimising the model code in terms of temporal inefficiencies in execution,
  5. Limiting data exchange to the data actually required for the respective modelling period,
  6. Parallel calculation of various processes.

2.4 General Overview of the SWISSland Model

SWISSland models both the sectoral supply and the sectoral demand for raw products. The "SWISS" of the name stands for StrukturWandel InformationsSystem Schweiz (= "Structural Change Information System Switzerland"). SWISSland has been used since 2011 to analyse agricultural policy issues. A website (www.swissland.org) and various publications giving detailed insights into the model organisation and the methodological approaches used already exist (Calabrese *et al.*, 2011; Ferjani *et al.*, 2014; Mack *et al.*, 2015; Mack and Hoop, 2013; Mack *et al.*, 2013; Mack *et al.*, 2011; Mann *et al.*, 2013; Möhring *et al.*, 2015; Möhring *et al.*, 2014; Möhring *et al.*, 2012; Möhring *et al.*, 2011; Möhring *et al.*, 2010a; Möhring *et al.*, 2010b; Zimmermann *et al.*, 2015). Figure 2.2 gives a schematic overview of the model.

Exogenous input variables are important components of the model, and are incorporated in the supply or demand module (Table 2.1):

The supply module illustrates the decision of the producers, whilst the demand module models the decision of the consumers (market actors). The interaction of demand and supply as well as foreign- trade effects determine the domestic market prices in several iterations. Finally, the SWISSland supply module uses an extrapolation algorithm to calculate sectoral parameters. These are primarily product quantities and various key structural and income figures, such as e.g. land-use and workforce trends, the number of farms, farm sizes and types, and income development according to the economic accounts for agriculture.

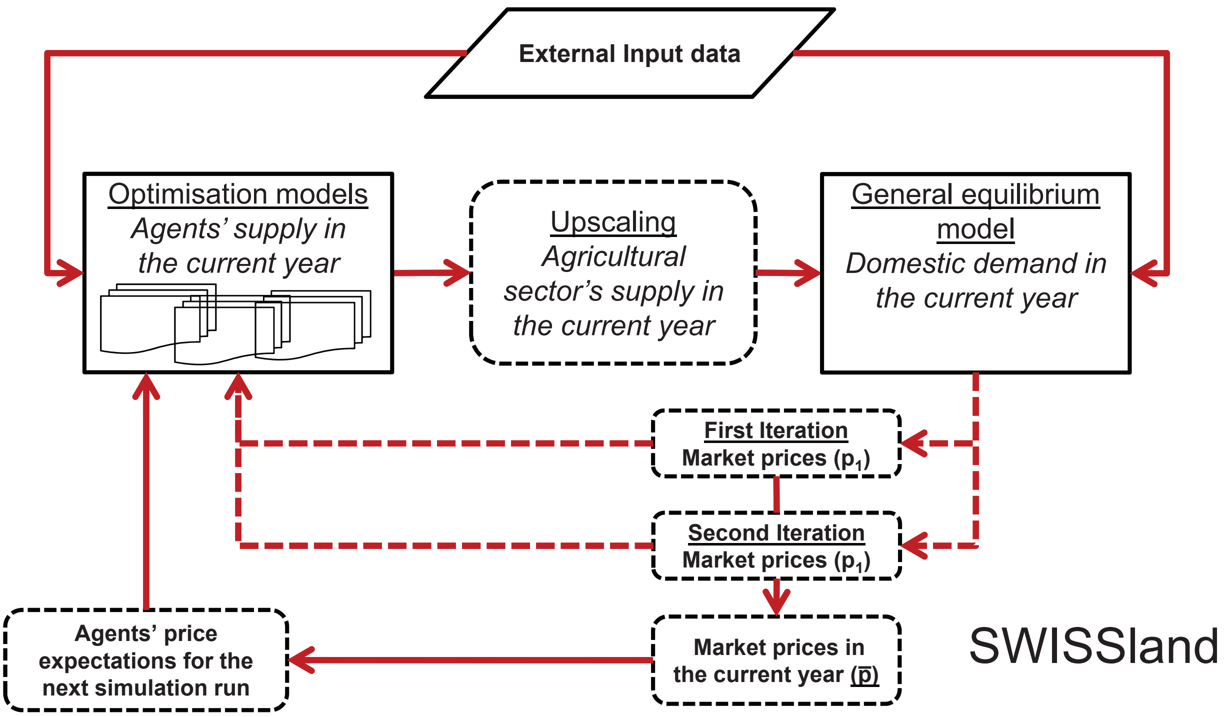

Figure 2.2: The SWISSland Model.

With the aid of a recursive dynamic approach, the SWISSland supply module optimises a population of around 3000 farms or agents in several iterations and for a variable period. The agents in the SWISSland supply module can alter their production programme, and accordingly, their resource use (land, labour, capital and animals), bearing in mind natural growth in earnings, price changes on the product and factor markets, and agricultural-policy transfer payments. Farm exits are possible as part of generation change. Optimisation causes farm managers to maximise their expected household income, which is the sum of agricultural and non-agricultural income.

Both modules in SWISSland – the supply module as well as the demand module – are calibrated to a relevant base year. The temporal resolution of a simulation run in the SWISSland model is one year, and thus corresponds to a farm's annual production planning. A recursive-dynamic model approach was expedient for the model. SWISSLAND is designed to simulate medium-term adaptation reactions of around 10–15 years.

Table 2.1: Exogenous input variables in SWISSland

Data		**Supply Module**	**Demand Module**
		Producers' Decision	**Consumers' Decision**
Agent-based Input Data	Non-agent entities and assumptions (e.g. development of crop yields) Agent-behaviour Agent spatial environment Agent life-cycle events Agent state Agent interactions	x	
Agricultural Policy	Direct-payment system	x	
Prices	Cost trend of the advance payments	x	
	EU- and world-market prices		x
Market Policy	Customs and border protection		x
Macroeconomic Framework	Population trend, exchange rate, GDP trend		x
Model Control	Process, rules, workflow	x	x

3 SWISSland Supply-Side Architecture

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3.1 Specification of agents' attributes for the initial year

The adaptive reactions of the individual agents are depicted in annual steps. Before the annual iteration process can be started, an initialisation step is necessary (Figure 3.1).

The initialisation process essentially consists of the following sub-steps:

- Improving the representativeness of the sample
- Importing the FADN data and other data sources
- Parameterising the individual-farm optimisation models
- Assigning attributes to the agents
- Calibrating the base year
- Assigning typical behavioral rules for individual agents or agent groups

The parameterisation of the agents in terms of location, farm structure and resource endowment is based on information obtained from the Swiss Farm Accountancy Data Network (FADN) data pool (2008–2013). This agent population is a sample of the approx. 50 000 family farms in Switzerland. Nevertheless, it ensures that the variability of the agent population in the model covers a broad spectrum of the heterogeneity of the basic population.

3.2 Specification of agents' attributes for the simulation years

3.2.1 Prices

The nominal producer prices used in the SWISSland supply module are based on the individual-farm prices ascertained in the bookkeeping system. Here, we are dealing with a combination of the gross price for the sale of the product and the price of the product when delivered internally to other agricultural activities, which can happen e.g. with the feeding or storage of self-produced feed grain on one's own farm (= an internal service). The producer prices of the base year are a three-year average. All product prices are based on price expectations derived from the previous year's prices. Each year, they are multiplied by the

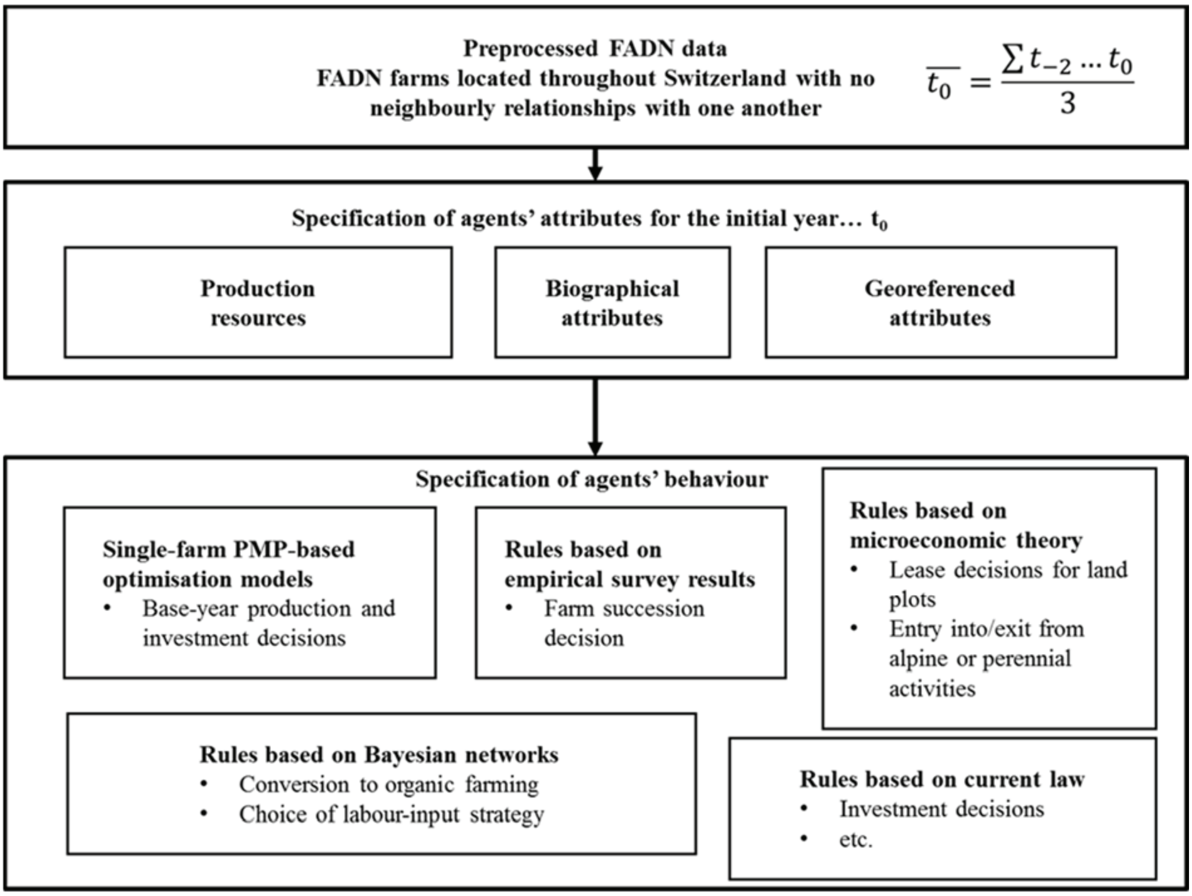

Figure 3.1: Overview of the initialisation process.

previous year's annual relative price trends, which are calculated in the SWISSland demand module.

The assumptions for the input cost trend (without feed) and investments (input prices) are prescribed exogenously, and are based on historic trends. The prices for feed are yielded endogenously to the model.

3.2.2 Yield increase in crop production and increase in annual milk yield per cow

In the base year, the harvested yields used in the model correspond to the average of the three accounting years which were combined to derive the base year. Here, the variability of the harvested yields results from the individual-farm site factors and the farm circumstances in each case (management, specialisation, crop rotation, etc.). Weather fluctuations and extreme years are not modelled.

In the past, some of the increases in harvested yields were considerable, especially in plant production. High-performance plant production in Switzerland and abroad suggests that yield increases are set to persist in future as well, even if future technical progress will not quite be on the scale of the last few decades. Since yield trends are closely correlated with time, trend calculations based on the statistical yield surveys of the Swiss Farmers' Union were carried out beforehand for the projection of per-hectare yields and milk-yield increases (SBV, 2000 to 2013). Consequently, yield trends in plant production are based on linear trend functons. The annual yield-increase factors used in the model represent the weighted arithmetic mean of the relative annual yield increases for the period 2000 to 2013, with said increases being corrected in the findings of an expert survey in accordance with the expressed estimates. In meat production (beef, veal, pork and poultry), no performance increases are expected, since it is less and less the maximum meat yield and more and more animal health that is the focus of attention.

3.2.3 Adjustments due to missing information

The agents make their production decisions based on yield and cost expectations derived from the three-year average of the production programme conducted in the base year and the product prices of the previous year. Expected costs, direct payments and expected yields were estimated for all non-existent agent production activities of the base year by estimating averages and standard deviations of the observed values of similar farms. These groups include farms in the same regions with similar farm types. This method is especially suitable for deriving the expected values for homogeneous farm activities such as commercial milk production or cereal production, since these are recorded in detail in the individual-farm accountancy data. The correct depiction of heterogeneous farm activities (such as e.g. vegetable production) which are underrepresented in the accountancy data and whose cost- and labour-requirement coefficients are not clearly assignable, is a trickier matter. In addition, various production processes of these farm activities often vary dramatically with respect to area output in monetary terms and working-time requirement, with the result that an aggregation of various processes to an activity in the model leads to distortions. A grouping of the farms is possible if – assuming a reference gross output per hectare of area – the actually achieved gross output of each individual farm (a) according to the documented turnovers ($GROSSOUTPUT_a$) is placed in relationship to this. The reference gross output is defined so as to illustrate the maximum possible gross output per hectare of the vegetable crops produced ($GROSSOUTPUT_{max}$).

$$OUTPUT_a = GROSSOUTPUT_a \,/\, GROSSOUTPUT_{max} \quad \textbf{(3-1)}$$

Based on the resulting factor ($OUTPUT_a$), the farm is now allocated to a group (Table 3.1; Q1–Q5). Each group represents a different level of management intensity. A low factor means low area output in monetary terms, whilst a high factor means a correspondingly high area output.

Table 3.1: Quantile boundaries for classifying vegetable-growing farms according to output per unit of area

	Lower Boundary	Upper Boundary
Q1		0.25
Q2	0.25	0.5
Q3	0.5	0.75
Q4	0.75	1
Q5	1	

For this, the assumption must be made that farms generally cultivate either predominantly labour-intensive or labour-extensive crops. A distinction between Proof of Ecological Performance (PEP) and organic farms is also necessary, since the organic farms achieve a higher contribution margin per hectare for many crops.

Inasmuch as cost- and work-requirement coefficients correlate with the monetary area output, we can in a further step use reference values to calculate the average working time spent or the average variable costs per unit of gross output produced for the activity in question.

Thus, in a further step, reference values (λ) derived from farm-data surveys conducted outside of the FADN network were used to calculate the average working time spent per gross output generated, or the average direct costs per unit of gross output generated. With the help of these values, we can now calculate the work-requirement ($\omega_{vegetables}$) and cost coefficients ($c_{vegetables}$) applied by the agent for the activity by multiplying them by the actual gross output of the farm (cf. Möhring *et al.*, 2012):

$$\omega_{vegetables} = GROSSOUTPUT_a * \overline{\lambda_{Akh}}$$
$$c_{vegetables} = GROSSOUTPUT_a * \overline{\lambda_c} \quad \textbf{(3-2)}$$

Where it is not possible to derive coefficients directly from the FADN data or to determine missing coefficients indirectly as mean values of the correspondingly assignable farm groups, statistically derived random numbers or standard data serve as a basis.

3.2.4 Time-related adjustments

At each time step, the age of both the farmer and the farm buildings is updated. The model uses a random distribution of farmer's age which was predefined within the initialisation process. Here, the age distribution of the agent population corresponds to that of the basic farming population (AGIS data). Since no information is available on the actual investment time, the initial age of existing farm buildings is an approximation based on the level of appreciation per LU.

3.2.5 Data flow

The data flow per simulation and for each iteration is outlined in Figure 3.2. The database combines three groups of data:

- Simulation-control data (for scheduling and data transfer between modules),
- Group-formation data (for forming population clusters and SWISSland municipalities),
- Decision-making behavioural datasets for each agent.

3.3 Specification of agents' behaviour

The modelling of agent behavior fundamentally influences the manner in which the actors make their decisions. The behaviour of the individual agents can be divided into smaller independent units ("microbehaviours") that are individually parameterised and modelled as autonomous processes (Kahn, 2007). Although initially this occurs independently of the sequence processes, it must subsequently be coordinated with them. Table 3.2 shows the behaviours previously modelled in SWISSland (categorised according to An, 2012). The methods for data collection are also provided.

3.3.1 Modelling production decisions

Rational agent behaviour is taken as an important basic assumption for modelling production decisions. Hence, each

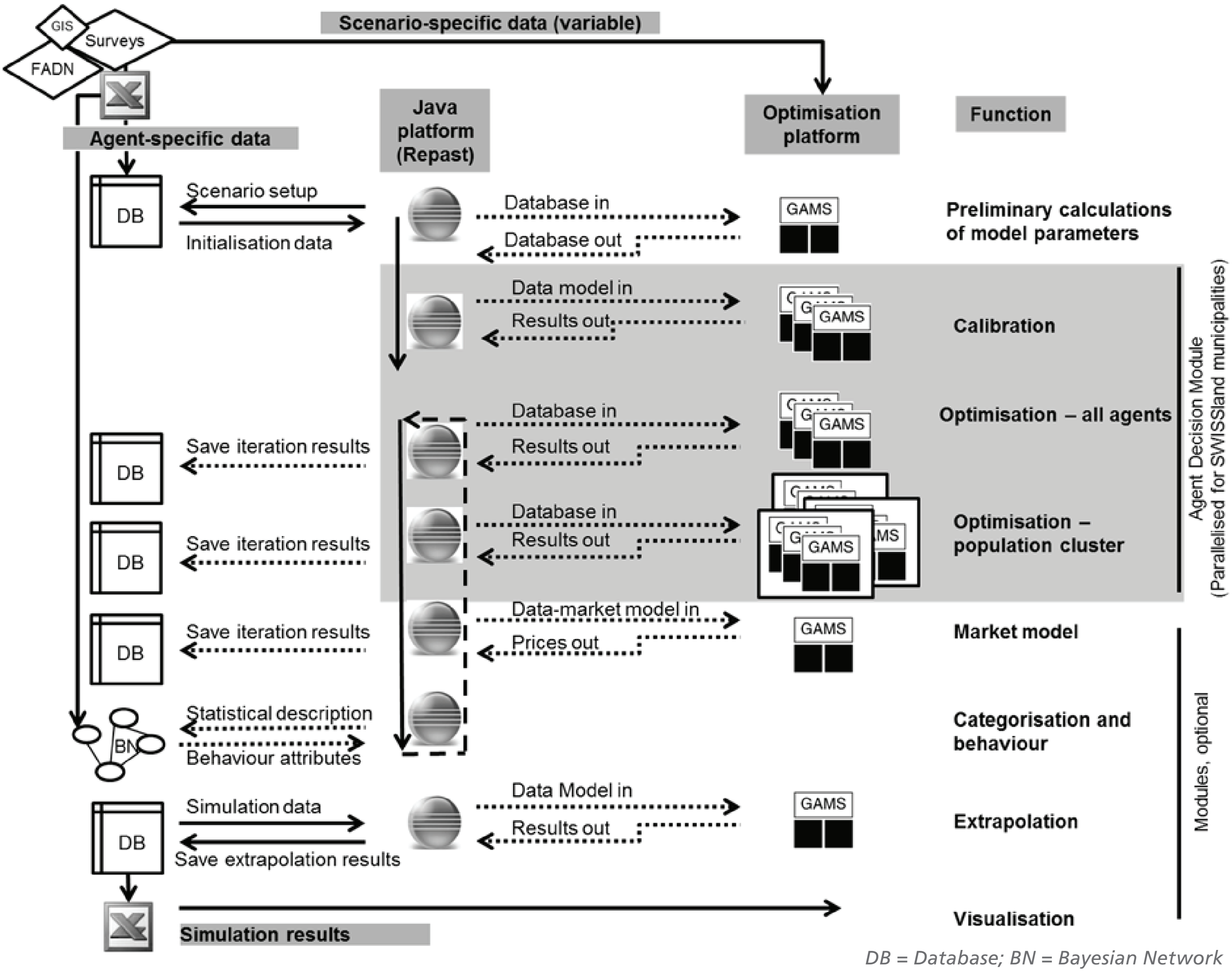

Figure 3.2: Data flow.

agent (Index a) maximises (max) its annual household income (INCOME) for each time period (Index t). In keeping with the theory of adaptive expectations, the agents (a) make their production decisions based on price (ρ) and yield (ε) expectations of the previous year for the various animal (Index l) and crop-production activities (Index g). Prices and yields were estimated for each agent on an individual-farm basis from the FADN data of the base year, with the price trends and average annual yield changes (Δ) being stipulated endogenously or exogenously for each time period. Household income results from the sale of agricultural products stemming from land use and livestock farming, from off-farm work, and from the proceeds of the direct payments less the means-of-production costs for crop- and animal-production activities (Equation 1). The level of the direct payments corresponds to the year-specific, production-dependent and production-independent approaches in each case, in accordance with current agricultural policy provisions.

Since we know that the functional form of the cost functions significantly determines the forecasting performance of our model, we tested different linear and positive mathematical programming (PMP)-based cost functions using an ex-post evaluation (Mack *et al.*, 2015). The term "positive" implies the use of observed data as part of the model calibration process. PMP-based cost functions use information contained in shadow values of a normative linear model which is bound to observed activity levels by calibration constraints. Based on these shadow values, a non-linear objective function is specified such that observed activity levels are reproduced by the optimal solution of the new programming problem without bounds. We use a functional form proposed by Howitt (1995) which models decreasing marginal gross margins based on increasing marginal costs in the objective function whilst returns to scale remain constant.

The ex-post evaluation clearly shows that linear cost functions for both crop- and animal-production activities lead to an overestimation of the most competitive production activities and substantially decrease the forecasting performance of the overall model, whilst PMP-based cost functions for crop-production activities show a much better forecasting performance. Because different PMP variants (variants estimate the matrix coefficients of the quadratic cost function on the basis of either maximum entropy or revenues) have a very similar forecasting performance, we decided to use the revenue method, which is much easier to implement in the overall model than the maximum entropy method. The ex-post evaluation also shows that linear cost functions for animal-production activities could improve forecasting performance where policy changes in the animal-production sector are more radical than in the crop-production sector. For scenarios with radical policy changes in the animal-production sector, the use of linear production functions in combination with the modelling of investment in new production branches constitutes a promising option.

For ex-ante evaluations, we have heretofore exclusively used positive mathematical programming (PMP) for both crop- and animal-production activities according to equations 2 and 3.

Table 3.2: Behavioural and decision models, data collection and scheduling aspects

Submodels	Behaviour	Data collection					Decision model					
		Sample survey (FADN)	Sample survey (representative)	Census data	GIS data	Bayesian Network	Microeconomic	Heuristic rule-based	Space theory-based	Institution-based	Preference-based	Hypothetical rules
Agent decision module	Production decisions	x					x			x		x
Farm manager's life cycle	Farm takeover, Farm exit		x				x	x			x	
Land market	Lease decisions for land plots			x	x		x	x	x			x
Growth and investment	Investment decisions	x					x			x		x
	Entry into/exit from alpine or perennial activities	x					x	x				x
	Strategy for shifts in labour input	x				x	x	x			x	
Land-use system	Conversion to another land-use system	x	x			x	x	x		x	x	
Alpine farming	Entry or exit, alpine activities	x	x		x		x		x		x	

$$Max\ INCOME_{a,t} = \sum_g p_{a,g} * \Delta p_{t-1,g} * \varepsilon_{a,g} * \Delta\varepsilon_{t-1,g} * LAND_{a,t,g} + \sum_l p_{a,l} * \Delta p_{t-1,l} * \varepsilon_{a,l} * \Delta\varepsilon_{t-1,l} * ANIMAL_{a,t,l} + \sum_i p_{a,o} * \Delta p_{t-1,o} * OFFFARM_{a,t,o} + \sum_d p_{d,a} * \Delta p_{t,d} * PAYMENT_{a,t,d} - COSTLand_{a,t} - COSTAnimal_{a,t} \quad (3\text{-}3)$$

subject to

$$\sum_g \omega^{LAND}_{a,g,w} * LAND_{a,t,g} + \sum_l \omega^{ANIMAL}_{a,l,w} * ANIMAL_{a,t,l} + \sum_f \omega^{LABOUR}_{a,f,w} * LABOUR_{a,t,f} \leq \beta_{w,a}$$

for all w ∉ g,l,f.

$$CostLand = \sum_g c_{g,a} * \Delta c_{t-1,g} * LAND_{a,t,g} - \sum_g d_{a,g} * LAND_{a,t,g} - 0.5 \sum_g Q_{a,g} * LAND^2_{a,t,g} \quad (3\text{-}4)$$

$$CostAnimal = \sum_l c_{l,a} * \Delta c_{t-1,l} * ANIMAL_{a,t,l} - \sum_l d_{a,l} * ANIMAL_{a,t,l} - 0.5 \sum_l Q_{a,l} * ANIMAL^2_{a,t,l} \quad (3\text{-}5)$$

The matrix coefficients *Q* of the non-linear cost term are based on revenues of the base year (*revenue**) and crop-production levels of the base year (*LAND**) , and uses supply elasticities equal to one, owing to the lack of empirical data (equation 4).

$$Q_{g,a} = \frac{revenue^*{}_{g,a}}{LAND^*{}_{g,a}} \quad (3\text{-}6)$$

For those production activities whose output is used on the farm itself, *Q* is calculated based on linear costs c and shadow values λ according to the German farm-type model FARMIS (Schader, 2009) (equation 5):

$$Q_{g,a} = (c_{g,a} + \lambda_{g,a})/LAND^*{}_{g,a} \quad (3\text{-}7)$$

The resource endowment (w) of a farm consists of the available area (Index g), the animal places on the farm (Index l), the other capacities limiting animal and crop production (e.g. sugar-beet quota, milk quota up to 2007, provisions concerning the receipt of direct payments), and the labour force (Index f). Further information on various policy restrictions regarding the receipt of direct payments is included in the model.

3.3.2 Modelling land-lease decisions

The 3000 FADN-based agents are located throughout Switzerland, and do not usually have a neighbourly relationship with each other. In a first step, land trade among these FADN-based agents was modelled by implementing a spatially realistic municipality structure that includes neighbourhood patterns among farm locations. In a second step, we assigned the agents to the farm locations in the municipalities. The third step involved modelling a plot-by-plot land lease of "exiting agents" to the remaining agents in the immediate vicinity based on heuristic rules. Chapter 3.3.3 describes the procedure in greater detail.

3.3.3 Modelling farm exit and succession

We use heuristic rules to model farm exit and farm takeover decisions. These rules were derived from various recently conducted studies examining structural change in Switzerland. From Meier *et al.* (2009), we know that in Switzerland, farm exit is shaped primarily by the farm manager's life cycle. Normally, once the farm manager turns 65 and starts receiving his state pension – which coincides with the lapse of entitlement to direct payments – the farm either closes down and the land is put up for lease, or the farm's production resources (i.e. land and capital resources) are transferred in their entirety to a family successor. Rossier and Wyss (2006) discovered that fewer than 10% of Swiss farm managers are older than the statutory retirement age of 65. The same source also informs us that over the past 15 years, and under the present policy scenario involving highly protected agricultural markets and one of the world's highest levels of direct payments, Swiss farms have only very seldom been given up before pensionable age is reached. Rossier and Wyss (2006) also determined that farm-succession decisions in Switzerland are significantly influenced by the number of sons in the family, and that 12 per cent of Swiss farm families do not have children. We also know from Rossier and Wyss that farm-exit and -entry decisions are significantly influenced by location (lowland, hill or mountain region), size and type of the farm, receipt of direct payments, and farm income. These findings have led us to establish four principal rules which drive agents' farm-exit and farm-takeover decisions:

1. Agents without sons will exit from farming and put their land up for lease. Since the number of children on each FADN farm is not known, agents without sons are determined randomly in each simulation run.
2. As long as their household income is greater than zero, agents exit from farming upon reaching pension age.
3. For scenarios with radical policy changes and significant drops in income, we assume that the agents exit from farming before they reach the pension age of 65 if household income is negative over a period of five years.
4. An agent's potential household income determines the subsequent agent's takeover decision. Only where the attainable household income of the agent is higher than an exogenously determined average regional minimum income will the successive agent take over the farm from his predecessor. This minimum income is based on an average reference income for the second

and third sector in Switzerland. A takeover of the farm's production resources (land and capital resources) by the "successive agent" occurs only when this income criterion is met.

In SWISSland, these rules are implemented in a two-stage decision-making process. In the first step, we select the number of agents with and without sons. The first group represents agents with potential successors, whilst the second group constitutes a percentage of the exiting agents. In a second step, the income criterion determines the takeover decision of the "successive agent". Farm succession and farm exit are therefore determined by the number of farms with potential successors, the rate at which agents reach pensionable age, and the percentage of successful takeovers, which in turn depends on income trends.

3.3.4 Modelling conversion to organic farming

A representative survey carried out by Ferjani *et al.* in 2010 revealed in detail the determinants that encourage or discourage farmers from farming organically in Switzerland. According to this study, when deciding whether or not to convert to organic production, Swiss farmers also weigh up considerations other than strictly economic ones. Behavioral aspects such as farmers' risk attitude and risk perception are particularly important in this context. In order to address the complexities of such a decision in the agent-based model, we integrated a Bayesian Network (BN) into SWISSland, which determines decisions to convert to organic and to conventional farming based on the survey results from Ferjani *et al.* (2010). This study surveyed organic and conventional farmers in Switzerland by means of questionnaires. Survey topics for both groups included farm structure (full-, part- or spare-time farm, type of production, farm size), personal data (age, sex, educational background), and attitudes towards and motivations for conversion. Most of the questions were closed alternative or multiple-choice questions, but farmers could expand on their answers, where appropriate. Hence, the data gathered were highly standardised and ready for statistical analysis. Farmers were also asked to describe their motives for adopting their current or planned farming system by selecting up to three out of the ten listed motives as being the most important ones for them. Respondents' attitudes to characteristics of organic farming compared to conventional farming were assessed through a series of statements which farmers were asked to rate on a Likert-type scale from "totally disagree" (1) to "totally agree" (7). To assess conventional/organic farmers' views on conversion, they were asked whether they planned to change to organic/conventional agriculture within the next five years. No specific premise such as "under the given political and financial circumstances" was stated, as this would make it difficult to give answers. The response categories were "yes, very sure," "yes, quite sure," "maybe", "probably not," and "no, absolutely not".

The variables used in the two Bayesian Network structures were divided into five groups: key characteristics of farmers, motives for the choice of farming system, farmers' attitudes, key characteristics of farms, and farmers' attitudes to future change (Table 3.3).

Bayesian Networks are a popular tool for reasoning under uncertainty. The BN method offers several interesting advantages: a) the possibility of using an incomplete dataset, thereby avoiding dependence problems between variables because the dependencies are encoded; b) the possibility of learning from data – in fact, when the causal relationships are expressed, the model can be used for an explanatory analysis; c) BNs combine Bayesian statistical techniques with domain knowledge and data, so it is possible – especially when data is insufficient or expensive – to add some prior information known by the researcher; d) the over-fitting of data is avoided when BNs are combined with other types of models (Heckerman, 1996). Figure 3.3 shows the graphical layout and the probability distribution of the network.

Agents converting to organic farming must comply with a wide range of organic-farming directives having a significant influence on inputs and outputs. To determine the production decisions of the converted farms, we assumed an adjustment of yields, direct payments, prices, labour demand and costs in plant and animal production, based on average percentage differences between organic and conventional farming.

3.3.5 Modelling labor-input allocation in the context of farm growth

Many agent-based models (Happe, 2004; Stolniuk, 2008; Sahrbacher, 2012) use normative optimisation approaches which distinguish between family and hired labour only for modelling labour input. These approaches are mainly driven by costs for hired labour and opportunity costs for family labour, whilst other labour-input strategies such as outsourcing by contractors are not taken into account. Nevertheless, on- and off-farm labour-resource allocation forecasts, which take into account not only the interdependencies among the use of family labour, external labour and contractors, but also their different flexibilities, require highly complex farm-optimisation models and data on transaction costs for the different labour categories (Beckmann, 1997). The Swiss FADN system does not provide such a database for modelling reliable labour-input decisions of the agent population, for which reason an alternative, empirically based method was developed to forecast the use of family labour, external labour, contractors and off-farm work. The forecast was based on a two-phase procedure. In the first phase, a Bayesian Network was used to estimate the agents' most likely labour-adjustment strategies, bearing in mind their production resources. In the second phase, the optimal labour-input strategies were determined in the optimisation process. Since SWISSland is a recursive-dynamic optimisation model, both routines proceeded in annual time steps. A cluster analysis was carried out to determine the most common labour-input strategies in Switzerland. The results of this analysis were used to set up the Bayesian Network and parameterise all observed labour-adjustment strategies in the single-farm optimisation model. The cluster results clearly demonstrated the interdependencies among family labour, external labour,

Table 3.3: Variables used in the Bayesian Network to determine conversion to organic farming

Group	Variable	Description
Key characteristics of farmers	Age	Classification of farmers by age
	Education	Education of head of household
Motives for the choice of farming system	Argument_Directive	Argument for and against directive for organic farming
	Argument_Income	Argument for increasing farm income
	Argument_RejectOrg	Sceptical attitude of farmers
	Argument_ Price	Argument for higher prices for organic products
	Argument_ Directpayment	Argument for greater public support of organic farmers
Farmers' attitudes	Attitude_Directive	Farmers' attitudes to organic directives: can also be too strict for some farmers
	Attitude_Income	Assessment of farmers about the ability of organic farming to increase income over the long term
	Attitude_Directpayment	Attitude to direct payment for organic farming
	Attitude_Price	Attitude to the additional prices achieved for organic products
	Organic_image	Farmer's perception of organic farming
Key characteristics of farms	Region	Location of the farm
	Farmsize	Farm size
	Livestocksize	Livestocknumbers
	Farm type	Type of farm
	Fulltime	Full-time farm
	Directsale	Option of selling direct
	Exit_Organic	Intention to exit from or stay in organic farming sector
Farmers' attitudes to future change	Change_Directive	Guidelines are changed frequently
	Change_Income	Change in farm income
	Price_Change	Change in the price of organic products
	Direct payment_Change	Change in direct payments for organic farming

contractors and off-farm work. The optimisation results showed that this method provides detailed forecasts for different labour categories.

3.4 Interaction of agents

Interactions take place mainly on the land market between exiting agents and a limited number of potential neighbouring agents, as well as when summered livestock is transferred between home and alpine farms.

3.4.1 Defining neighbourly relationships for FADN-based agents

The municipality structure is based on seven existing Swiss municipalities. These seven reference municipalities were chosen from among Switzerland's 2765 municipalities in a two-step procedure. Firstly, a municipal typology was created on the basis of size (utilised agricultural area or UAA), difference in altitude (between the lowest and highest points above sea level of the UAA), and distribution of the farmland over different altitude levels within a municipality. These attributes were selected because they determine the accessibility and the driving time between the farm locations and the plots of a municipality. The horizontal and vertical distances between the farm locations and the plots were estimated for Switzerland's 2765 municipalities. On this basis, five municipality groups were selected to which all 2765 Swiss municipalities were assigned (Table 3.4). Secondly, taking the representativeness of farm type and size into account, at least one genuinely existing municipality per group was chosen, and specific georeferenced data (topology of the plots cultivated on each farm, location of the farm buildings) were determined for each farm in the municipality. Data were processed in a GIS in order to generate information on distances from farm buildings to plots, as well as on neighbourhoods, plot size, and form of cultivation. The main selection criterion for the reference municipalities was the availability of georeferenced data for all farm locations and fields within the municipality (Table 3.5). The farms located in the reference municipalities served as a source of information for the description of the FADN-based agents in terms of spatial and topographic characteristics.

To model land trade among the FADN-based agents, each agent was assigned to a matching farm location in a reference municipality (Figure 3.4).

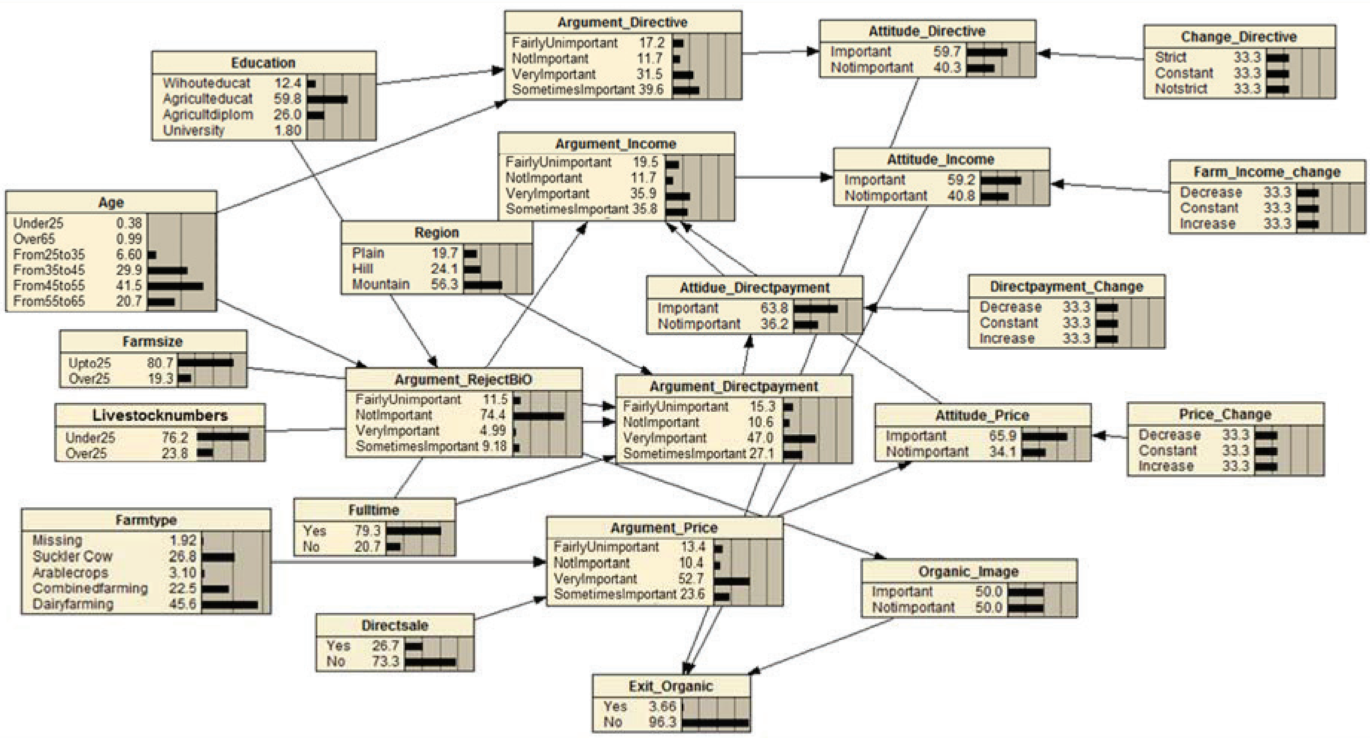

Figure 3.3: Example of graphical representation of the network, and marginal probabilities that the variable states will predict the likelihood of the exit of organic farms from the sector.

Table 3.4: Description of the municipality groups

Municipality Group m	No. of Municipalities per Group	Average UAA (ha)	Standard Deviation UAA (ha)	Average Difference in Altitude (m)	Standard Deviation of Difference in Altitude
1	1016	316	301	90	54
2	571	411	273	231	132
3	480	614	627	372	131
4	350	1125	928	1421	389
5	334	1223	1565	1381	377

UAA: Utilised Agricultural Area

Source: Own calculations

Table 3.5: Features of the reference municipalities

Name of Reference Municipality	Municipality Group m	UAA (ha) per Reference Municipality	No. of Plots per Reference Municipality	Difference in Altitude (m)	No. of Farms per Reference Municipality	Total No. of Reference Municipalities in the Model
Oberembrach	1	591	394	202	31	9
Illnau-Effretikon	2	1158	735	197	54	7
Vechigen	3	1467	799	396	102	7
Trimmis	4	479	995	1961	49	14
Alpnach	5	922	729	1551	78	7
Engelberg	5	722	483	1823	58	8
Giswil	5	1181	1076	1727	109	7

Source: Own calculations

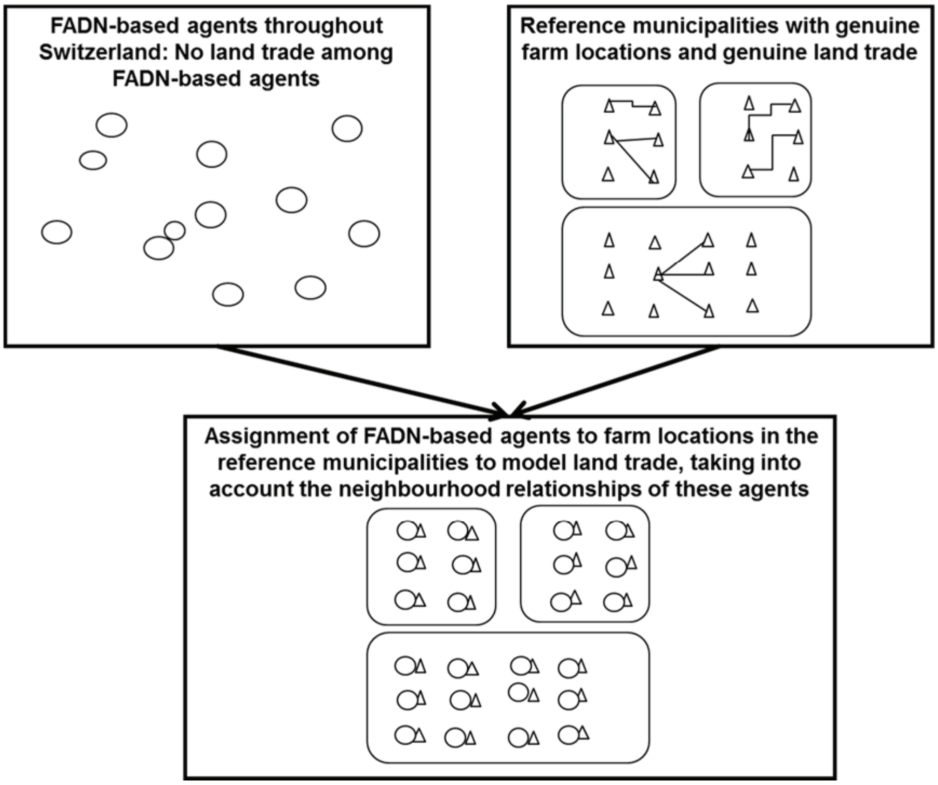

Figure 3.4: Assignment of FADN-based agents to farms in reference municipalities to model land trade.

The principal criteria for the assignment of FADN-based agents to farm locations of the reference municipalities were matching attributes which were present in both datasets, particularly farm area (ha UAA, ha grassland, ha arable land), altitude (m.a.s.l.) and the zones to which they belonged (lowland zone to mountain zone 4). Because the number of FADN-based agents was significantly higher than the number of farm locations in the reference municipalities, our first step was to duplicate the reference municipalities which were underrepresented in terms of these allocation features. This was done by minimising the sum of the squared deviations between the attributes of the FADN-based agents and the farm locations of the reference municipalities. Because over half of all FADN-based agents had farm locations in a reference municipality of group 5, taking one reference municipality for group 5 into account would require approx. 20 duplications per municipality. In order to limit the number of duplications per municipality, it was decided to take three genuinely existing municipalities into account for group 5. The duplication procedure led to the total number of 59 SWISSland municipalities (last column of Table 3.5).

An advantage of this method is that it allows the topology and the distances between plots to be modelled highly realistically, despite the difficulty of ensuring the representativeness of all features (topography, UAA per municipality, farm type, zone). The 3400 FADN-based agents were assigned to the actual farms of the SWISSland municipalities by minimising the sum of the squared deviations of these attributes between the FADN-based agents and the actual farm in each case. The allocation of agents to the 59 municipalities could in turn be formulated as an optimisation problem. The binary solution variable of such a system would, however, be a matrix in the "No. of agents * No. of farms in the reference municipalities" dimension, which would overtax the available solution capacities. Assignment is therefore via a gradual loop formulation in which each agent is successively assigned to the most suitable farm in the reference municipalities in each case that is not yet taken. The most suitable farm in each case is the one with the smallest deviations in its attributes. In the event of unequal size representations of the attributes, this process could result in no suitable actual farm in the reference municipalities still being available for the last agent to be allocated to. Because of this, the attributes of both the agents and the farms of the reference municipalities are transformed beforehand into rank values. In this way, and because it leaves several farms of the reference municipalities to which the last agent can be allocated, an adequate distribution result is achieved.

Since the most important criterion for the assignment of the FADN-based agents to the farms of the SWISSland municipalities was the matching of the attribute "farm area", differences in farm size between the agents and the farms of the reference municipalities were very small. Where minor differences existed, reference-municipality farm plots were uniformly scaled up or down so that farm area corresponded exactly to that of the relevant FADN-based agents. In addition, several other FADN-based agent attributes (e.g. percentage of arable land; percentage of slopes and steep land) were transferred to the allocated plot structures.

Consequently, all FADN-based agents are determined by spatial characteristics (farmyard coordinates; number of plots with meadows and arable land; coordinates of the plots and their field-farmyard distance), and ultimately possess "virtual" neighbouring agents whose plots border on other agents.

3.4.2 Modelling Land Exchange and Lease Pricing

A precondition for land trade among agents is a neighbourly relationship. Because such a relationship derives from farm locations within a municipality, land-trade modelling is limited to agents whose farm locations are in the same municipality. "Exiting agents" having no farm successor to whom they can hand over, or whose potential successor decides on economic grounds against taking over the farm, offer plots to the remaining agents in the immediate vicinity. Empirical studies conducted in two regions of Germany (Strohm, 1998) show that the number of farms involved in the lease market is limited, ranging between one and five. According to the findings of Strohm (1998), it was assumed that the five nearest neighbours would be involved in the bidding process. Only in the event of no agent being found were three further neighbours considered. These restrictions on the number of bidding agents in the same municipality limit the number of optimisation runs to an acceptable range. A stepwise 20% reduction in lease prices was also stipulated in order to limit the number of optimisation runs. The five nearest agents to an exiting agent constitute the group of agents interested in the latter's plots. Decisions to allocate land to the neighbouring agents as well as lease pricing are modelled as a plot-by-plot bidding process: The initial lease price asked by an exiting agent is based on the average regional values of the FADN farms for arable land and grassland in the base year. Because these regional averages are close to the compulsory upper limits for rental prices that are measured against the productive value of the land, these values are also taken as upper limits for regional lease prices.

An agent's lease decision for a plot depends on said plot's income growth. As the supply of plots rises, other production resources such as labour generally exert a limiting effect, causing the plot-based economic benefit to decline. To calculate the increase in income of all neighbouring agents involved in the bidding process, each of these agents is optimised with the new plot. The neighbouring agent receives the plot which generates the highest profit at the upper limit of the lease price. If, however, the upper limit of the lease price is higher than the increase in income of all agents in the near vicinity, the bidding process is repeated, taking other agents in the wider vicinity into account. Where the upper limit of the lease price is also too high for agents in the wider vicinity, it is assumed that the exiting agent will reduce the lease price in steps, and that the bidding process will recommence. Should the situation arise where the lease price is greater than zero and no neighbouring agent is able to generate a profit for a plot, the plot becomes fallow land. Provided that a neighbouring agent benefits from leasing only when the lease price is zero, it is assumed that the exiting agent leaves the neighbouring agent the plot before it becomes fallow land.

3.4.3 Home agents with livestock for transfer to alpine pastures

Each farm can have its livestock grazed on an alpine farm during the summer months. The alpine farm is likewise optimised as an individual agent in its own single-farm model. If the animals spend the summer on the mountain pastures, they make capacity demands on grazing area and fertilised land, as well as on the labour and equipment of the alpine farm over the relevant time period. It is therefore essential that the capacity demands of the summered animals in each case be divided up proportionally such that, over the relevant time period, they are taken into account solely by the alpine farm, rather than by the agent of the home farm. At the same time, this affects the scope of the production activities on the home farm, since the latter's capacities in the summer months are only utilised by the animals present. Thus, for example, it may be that certain conditions for complying with the limit values for receiving direct payments can only be met since livestock numbers on the home farm are lower during the summer months. Likewise, both the feed requirement and the working-time requirement on the home farm decrease when animals are summered on alpine farms. As a rule, the livestock population of the home farm consists of animals that are "non-summered", "summered on the privately owned alp", and "summered on the communal alp". The coefficient indicates the individual categories' relative share of the overall livestock population of the home farms.

If a farm has its own summering land, the privately owned alp is utilised to maximum capacity to graze its livestock. Furthermore, it is assumed that farms without their own summering land, but with summered animals, graze the latter on a communal alp over the summer months. For this case, an allocation algorithm is formulated in the model which assigns the animals as a function of transport distance, expansion of infrastructure and accessibility, and the capacity of the alp. Consequently, alpine farms with a high expansion of infrastructure and ease of accessibility are more likely to be used to graze livestock.

3.5 Process overview of the model

The iteration process is then started, with the model flow depicted in Figure 3.5 applying for each time interval. The technical implementation of the process is described in chapter 6.2.

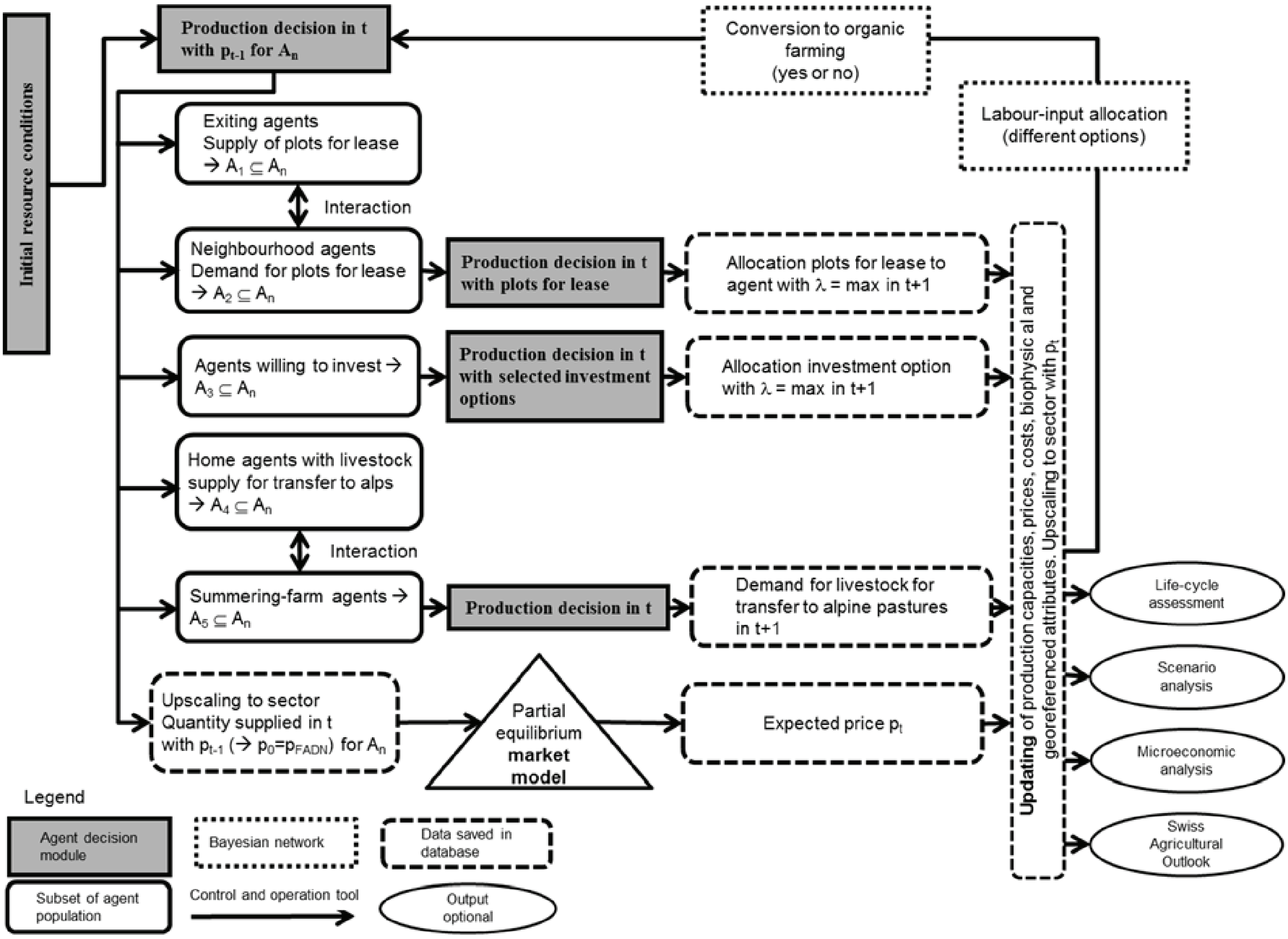

Figure 3.5: Design and process overview of SWISSland.

3.6 Overview of individual-farm optimisation models

The agent decision module depicts the individual farm with all its specific production and income options, bearing in mind the resource endowment in each instance. Essentially, this encompasses agricultural production, additional income and direct payments. Forestry and para-agricultural activities are encompassed within the scope of the base year and are continued, but do not form part of the agent's decision matrix in the forecast years (Table 3.6).

All exogenous coefficients are assigned in Greek letters. The following coefficients are contained in the model:
ß = Resource endowment
ω = Factor coefficients of demand/Resource utilisation
ε = Livestock-production coefficients
φ = Feed coefficients
θ = Fertiliser-nutrient coefficients
ν = Animal-place coefficients
o = Management options

3.6.1 Land balances and fodder limits

The resource endowment (ß) of a farm consists of the available area (Index g), the animal places on the farm (Index l), the other capacities limiting animal and crop production (e.g. sugar-beet quota, milk quota up to 2007, provisions on the receipt of direct payments), and the labour force (Index f). Here, the factor endowment of the farm acts as a limiting factor, since the factor utilisation must not exceed the available capacity.

In terms of the land restrictions, the following conditions apply:

$$\sum_g (\omega_g^{LAND} * LAND_g) \leq \sum_g \beta_g \qquad \textbf{(3-8)}$$

for all g; ω ϵ g.

- An agent uses its (owned plus leased) land according to the respective land-use categories (field crops on arable land, grassland crops on grassland), it being permissible for grassland to be converted to arable land, but not for arable land to be used as permanent grassland.

- Base-year pasture grassland may not be converted to meadow.
- Base-year extensive green feed cannot be intensified.
- Base-year extensive pasture cannot be converted to intensive pasture.
- Because of the different zone-dependent growing seasons, 100% use of pasture is not possible in Switzerland.
- The Proof of Ecological Performance (PEP) crop-rotation restrictions for receipt of direct payments must be obeyed.
- Some crops are fixed to the base-year quantities and cannot be expanded over the course of time. Among these are wooded areas, alpine farming areas and standard fruit trees, areas under vines, hedges, and litter meadows ("Streuwiesen"). Development of these areas is therefore underestimated in SWISSland over the projection period.
- The sugar-beet quota per farm is adjusted annually, since quotas of exiting farms are divided up among the remaining agents.
- The cultivation of extensive arable crops is possible (extensive production) and can be extended.

3.6.2 Livestock balances

Livestock balances ensure that the sum of the sold, reproduced and outgoing animals is equal to the sum of the produced and purchased animals. Reproduction is only entered on the "dairy-cow branch" balance sheet (Index k). In this context, female offspring can either be used internally to replenish the herd, or allocated to other activities (e.g. cattle fattening). Alternatively, they can be sold. In the case of internal supply, the coefficient matrix (εl) takes a plus sign; for internal demand, a minus sign.

(3-9)

$$SALE_k + REPRO_k - \sum_k PURCHASE_k \leq \sum_k \left(\varepsilon_k^{ANIMAL} * ANIMAL_{l=k}\right)$$

for all k, k ϵ l.

For all other livestock branches, the scope of the production activities is derived solely from livestock numbers from the base-year accounts and from the available animal places.

A distinction is drawn between animals remaining throughout the year on the home farm and those spending a certain amount of time on the alpine pastures, since this

Table 3.6: SWISSland individual farm optimisation model matrix

		Plant production (LAND)	Animal husbandry (ANIMAL home)	Animal husbandry alp (ANIMAL Alp)	Purchase	Sale	Investment	Family labour	Employees	Utilisation	Sideline	Options	RHS
		c	c	c	c	c	c	c	c	c	c	1	
	Household income	Objective-function coefficients											Max.
Factor capacities	Land (ha)	Technical coefficients											Capacities
	Roughage land and fodder (ha)												
	Animal husbandry (places)												
	Reproduction (LU)												
	Labour (SWD)												
	Sugar-beet quota												
Ecological restrictions	Rotation (% of UAA)												
	Ecological compensation area (% of UAA)												
	LU stocking rate (LU/ha)												
	Nitrogen balance (kg N)												
Direct payments	RCLU stocking rate (RCLU/ha)												
	Grassland-based milk production												
	SLU												
	Access authorisation for direct payments												
Other	Growth pattern												

Note: c = continuous activities; SWD = standardised working day; SLU = standardised labour unit has an impact on the capacity utilisation of the home farm over the summer grazing period. For example, less work is required on the home farm if a proportion of the animals are fed on the alpine farm. Moreover, less organic fertiliser is produced and less fodder must be provided on the home farm during the alpine summering season.

The coefficient ε_l^{ANIMAL} indicates the individual categories' relative share of the overall livestock population of the home farms:

$$\sum_l \varepsilon_l^{ANIMAL} * ANIMAL_l \leq \sum_{alp} ANIMAL_{alp} + \sum_{heim} ANIMAL_{heim} \tag{3-10}$$

3.6.3 Fodder balances

Roughage balances are calculated in SWISSland. Grassland activities must at minimum produce the demand for roughage per animal and year.

$$\varphi_{\mathrm{RCLU}}^{ANIMAL} * ANIMAL_{\mathrm{RCLU}} \leq \sum_g \varphi_g^{LAND} * LAND_g + BUYROUGHAGE - SALEROUGHAGE \tag{3-11}$$

for all RCLU; RCLU ϵ l.

The following main assumptions apply for feed balances in SWISSland:

- The feed balances are modelled "on the basis of the base year", using the dry-matter (DM) content. A fundamental change in the nutrient content and ingredients (MJ NEL, protein, etc.) of the basic-ration components cannot be offset by adjusting the concentrate components; however, we bear in mind that the total concentrate cost in DM increases with increasing milk yield per cow.
- In SWISSland, the demand for feed is determined by the animal population and the domestic supply of feed. The result is an average producer price for various concentrates which are returned from the demand module to the supply module. This concentrate price corresponds to an average price composed of low- and higher-priced concentrate components. Price increases for concentrates make milk-yield increases more expensive in reality, which is why the latter are less profitable unless expensive feedstuffs are replaced by cheaper ones in the feed ration. SWISSland does not optimise any feed rations, and hence cannot depict this relationship sufficiently accurately.
- The percentage of pasture fodder in the ration depends on the zone-dependent growing seasons, and can therefore not be extended at will.
- Farms can in addition buy or sell roughage and hay, but only if they have already done so in the base year.

3.6.4 Nitrogen balance

The SWISSland nitrogen balance was prepared according to the fertilisation standards of the "Suisse Balance" programme. As described in Chapter 5.3 manure nitrogen content and plant nitrogen demand were estimated according to Flisch *et al.* (2009). For input, the N-input of fertilisers and feedstuffs is estimated by fertiliser cost per area and fertiliser recommendations. To account for the uncertainties of different manure types, the N-content of the manure had a correction factor based on the assumption that farms met the requirements of the "Suisse Balance" programme in the first year. The N-requirement of crops may be exceeded by 10%.

$$\sum_g ((\theta_g^{LAND} * LAND_g) - SELLMANURE) * 1.1 \tag{3-12}$$

$$= \sum_l (\theta_l^{ANIMAL} * ANIMAL_{Heim}) + BUYFERTILISER + BUYMANURE$$

3.6.5 Labour balance

The Swiss FADN system provides the number of family-labour units and wage-labour units employed on the farm, as well as the number of family-labour units working off-farm, in annual working units on a self-disclosure basis. Farm expenditure for labour and machine use by third parties as well as revenues for labour and machine use on neighbouring farms and non-agricultural income from off-farm work is also available in the FADN system (Hoop *et al.*, 2014). As already mentioned in Chapter 3.3.4, the labour-input decisions of the agent population were developed in a Bayesian Network to forecast the use of family labour, external labour, wage labour of third parties, wage labour for third parties, and sideline (see also Mack *et al.* (2013) and Hoop *et al.* (2014)). Labour supply on the farm includes on-farm family labour and wage labour. The demand side is determined by labour demand of crop- and livestock-production activities. Depending on the labour-input strategy derived by the BN, further labour demand required for farm growth will be covered either by additional utilisation of on-farm family labour, or additional wage-labour supply. With increased use of outsourced labour, on-farm labour demand decreases whilst rising variable costs must be borne in mind in the objective function coefficients.

All seven identified labour-adjustment strategies were implemented by a set of alternative labour-decision variables defining the extent of changes in labour capacity within a single time period. The following labour-adjustment strategies (LABOUROPTION 1–7) are considered in the model:

1. Sideline dropout
2. Sideline-oriented
3. Family labour-focused
4. External labour-focused
5. Outsourcing-focused
6. Wage-labour supplier
7. Wage-labour dropout

Apart from these strategies, an agent always has the option of not making any changes (the no-change option). Labour-decision variables were restricted to one unit in the optimisation model (see Table 3.7). Distinct strategies could be combined into one unit in total. Farms are eligible for direct payments in Switzerland only when 50% of the entire farm workload is borne by family or non-family labour.

$$FAMILYLABOUR + EMPLOYEE = LABOURSUPPLY \qquad \textbf{(3-13)}$$

$$\sum_g PPLABOURUSE_g) = \sum_g (\omega_g^{LAND} * LAND_g) \qquad \textbf{(3-14)}$$

$$\sum_l TPLABOURUSE_l) = \sum_l (\omega_l^{ANIMAL} * ANIMAL_l) \qquad \textbf{(3-15)}$$

$$\sum_l TPLABOURUSE_l + \sum_g PPLABOURUSE_g + \sum_o REDUCTION_o + \leq LABOURSUPPLY \qquad \textbf{(3-16)}$$

$$LABOURSUPPLY \leq \beta * LABOUROPTION_o \qquad \textbf{(3-17)}$$

$$LABOUROPTION_o = 1 \qquad \textbf{(3-18)}$$

Table 3.7: Modelling labour strategies in SWISSland's single-farm optimisation model

			Plant and animal husbandry and other activities	Family labour	Employees	Sideline	Labour option (1-7)	No-change option		RHS
	Household income		+/-		-	+			=	Max
Labour capacities	Family labour on the farm	ALU	+	-			+/-		<=	+
	External labour on the farm	ALU	+		-		+/-		<=	+
	Wage labour for third parties	CHF	+	-			+/-		<=	+
	Wage-labour of third parties	CHF			-		+/-		<=	+
	Sideline	ALU				+	+/-		<=	+
	Labour option (o)						+	+	=	1

ALU = annual labour units

3.6.6 Direct-payment system

In SWISSland, both the direct-payment system in force until 2013 (AP 2011 [A]) as well as the currently valid system (AP 14–17 [B]) were modelled (Direct Payment Ordinance, DZV; SR 910.13).

The following limits are incorporated in the model:

- The whole-farm minimum labour requirement in standard labour units for the receipt of direct payments is 0.25 SLU (for A and B).
- The farm manager's age for entitlement to direct payments is "not over 65 years" (for A and B).
- The ceiling for paid-out direct payments per standard labour unit is CHF 70 000 per year (for A only).
- Maximum stocking density per hectare green area for receipt of TEP and RCLU payments must be maintained, with an individual-farm stocking limit based on differentiation by zone and a summering-land surcharge being taken into account. In addition, each farm complies with the deduction for marketed milk (for A only).
- Summarised balance sheets ensure that farms reaching the operational ceilings can nevertheless keep additional animals or farm additional land. In other words, non-entitled animals plus direct-payment-entitled animals yield the number of animals in total, and non-entitled land plus direct-payment-entitled land yields the total cultivated area of the farm (for A and B).
- No project-based or spatially-explicit-oriented direct payments of AP 14–17, including subsidies for quality of landscape, biodiversity (quality level 2) or efficient use of resources (for B only), can be mapped with SWISSland. The corresponding payments for the sector are therefore considered exogenously in SWISSland.

3.6.7 Investments

The number of animals of all species in the model is limited by the number of animal places.

$$\sum_l \omega_{l,v}^{ANIMAL} * ANIMAL_{a,t,l} \leq \sum_v \beta_v^{BUILD} * BUILD_v \qquad \textbf{(3-19)}$$

for all v; v ϵ ω.

Here, only as many animals as there are animal places available can be kept. The coefficient , $\omega_{l,w}^{ANIMAL}$ serves to calculate the animal-place capacity requirement for alpine animals as well as for rearing or fattening livestock with several activities per year.

Because of the PMP calibration approach, the individual-farm optimisation models of the SWISSland supply module have a nonlinear cost function. The advantage of this approach consists in that it does not permit an extreme expansion of individual activities in the optimal solution, and thus indirectly takes into account monetary and non-monetary advantages of the activities which, although available in reality, can for various reasons (missing information, lack of measurability, etc.) not be borne in mind in the model. On the other hand, this modelling approach is disadvantageous if bigger changes in the production programme are to be simulated into the future. This is the case with investment modelling. Strong individual-farm growth within a short timeframe, or the entry into or switch to completely new, previously unobserved branches of animal husbandry is hampered by the applied modelling method of investment in expansion. True, this decreases the flexibility of the operational decision-making matrix, but also enables individual-farm growth, since the farms can continually expand their housing by individual barn places. The average annual costs per animal place are then taken into account in the objective function, with the variable annual costs being adjusted via a cost-trend factor. In this variant, the old barns can continue to be used.

$$\sum_{v} BUILD_v = \sum_{old} BUILD_{old} + \sum_{new} BUILD_{new} \qquad \textbf{(3-20)}$$

The old barns continue to be managed, to the extent that this is economically profitable. Capacity reserves that are available in practice but that are not recorded in the bookkeeping data are not modelled. A built-in "scaling factor" ensures that efficiency gains, e.g. through improved utilisation of work capacity and in the case of investments in new barn places or land lease, are borne in mind.

3.7 Upscaling method

Following the model run, the model results of the entire agent population are extrapolated at sectoral level with the aid of a weighting process. SWISSland calculates sectoral parameters via an extrapolation algorithm. Various sectoral output indicators are of interest: product quantities and prices, land use and labour trends, income trend according to the Economic Accounts for Agriculture, sectoral input and output factors for calculating environmental impacts, and important key structural figures such as number of farms, sizes and types of farm, or number of farms switching farming system. Zimmermann *et al.* (2015) compared various upscaling alternatives for the model. Different model types are faced with different challenges in adequately representing the whole sector.

Traditional models have usually depicted the agricultural sector as a virtual large farm, or as subdivided into regional farms. Neither inter-farm relationships nor heterogeneous individual-farm decisions can be taken into account in such models sufficiently, if at all. This subsuming of individual farms into larger units could therefore be expected to produce sizeable aggregation errors (Brandes, 1985; Table 3.8). When modelling similar farms as farm types or average farms, this aggregation error can be reduced (e.g. FARMIS: Bertelsmeier *et al.*, 2003). Often, however, such a farm model is not based on the basic population of farms (e.g. since data are not available from all farms). In such cases, a sampling error arises which characterises the difference between the true values of the basic population and those of the extrapolated sample. If a random sample is not possible, representativeness can be improved by a strategic selection of typical farms (Happe, 2004). Only when all farms of the basic population are included in the model can aggregation and sampling errors be avoided.

Table 3.8: Possible representation errors for the entire region in various sector models

Model Type		Aggregation Error	Sampling Error
Regional farm	Entire region as virtual farm	+++	(-)
Farm types	Groups of average farms	++	+
Farm sample	Representative selection	(-)	++
	Non-representative selection	(-)	+++
	Complete coverage of the region	(-)	(-)

+++ = strong probability; ++ = some probability;
+ = weak probability; (-) = no probability

An essential aim of the SWISSland model is to forecast structural change in Swiss agriculture. Structural change is a result of decisions taken at individual-farm level. A multi-agent model depicting all of the approx. 50 000 farms in Switzerland would be hard to implement, however, since the necessary data are not available from all of the farms, and the high volume of data and long computer run times would make application extremely difficult. For these reasons, SWISSland only depicts a sample of all farms, which makes an extrapolation necessary for sectoral statements.

Our objective is to progress from the individual-farm results of a model to a regional, sectoral or structural level. Hence, we need to develop a method that reflects both the reactions of the farm model and the official numbers from the statistics as faithfully as possible. This method must be based on attributes that are available both from the individual farms and from the basic population. In Switzerland, only structural attributes such as surface areas of cultivated crops and livestock numbers are systematically collected from all farms. Economic figures are only available from the FADN farms. A comparison of important structural attributes for the basic population and for the farm sample indicates that some attributes are strongly under- or over-represented. The percentage of small-sized farms and the surface areas of permanent crops are much lower in the sample, whilst the dairy-cow population is higher. The average area of an individual farm is also higher in the sample (Zimmermann *et al.*, 2015).

The aim of the extrapolation is to apply the results of the sample-based model to the appropriate basic population, using specific methods. For this, a suitable weight is generally sought for every micro-unit (individual farm) of a micro-database (sample). Consequently, the sum of attributes formed in each case with these weights should correspond as closely as possible across all micro-units to the given data of the basic population. In the literature, different objective/distance functions are utilised for this, such as generalised least squares and minimum information loss. In this optimisation process, the extrapolation factors can be determined by minimising the deviations either from initial extrapolation factors or from the statistical characteristics.

In multi-agent models where relationships such as land trade exist between the agents, however, the allocation of individual-farm extrapolation factors can lead to inconsistencies in the extrapolation: Land trade between farms to which different extrapolation factors are assigned leads to a change in the stipulated total area (Figure 3.6, column 2). This change in area can be corrected by a corresponding adjustment of the farm extrapolation factors, i.e. the factors are adjusted so as to leave the extrapolated total area unchanged (Figure 3.6, right). At the same time, however, such a correction has repercussions for the extrapolation of all remaining farm attributes, whose extrapolated values would change not because of the model calculations, but simply because of the correction of the extrapolation factors. To prevent such inconsistencies, the proxy of the farms in the agent population could be adjusted beforehand to the proxy in the basic population, based on the initialisation method of Happe (2004). Unlike in Happe (2004), however, the number of certain farms would not be multiplied until the entire region was covered. Instead, farms from under-represented farm groups would be multiplied and some from over-represented groups would be removed from the agent population, if necessary. The goal of this adjustment is for a similar percentage of all essential attributes to be represented, allowing the results of model calculations to be extrapolated to the basic population with a general, fixed factor.

The lessons drawn from the analysis described in Zimmermann *et al.* (2015) can be grouped into two categories: those drawn for improving the SWISSland model, and those drawn from a purely methodological perspective. Starting with the second category, applying optimisation models in such a way as to allow comparison with observed developments has been shown to be potentially helpful. This is probably the only way to normatively compare different methodological options that are all theoretically plausible. Furthermore, a validation process in which diffe-

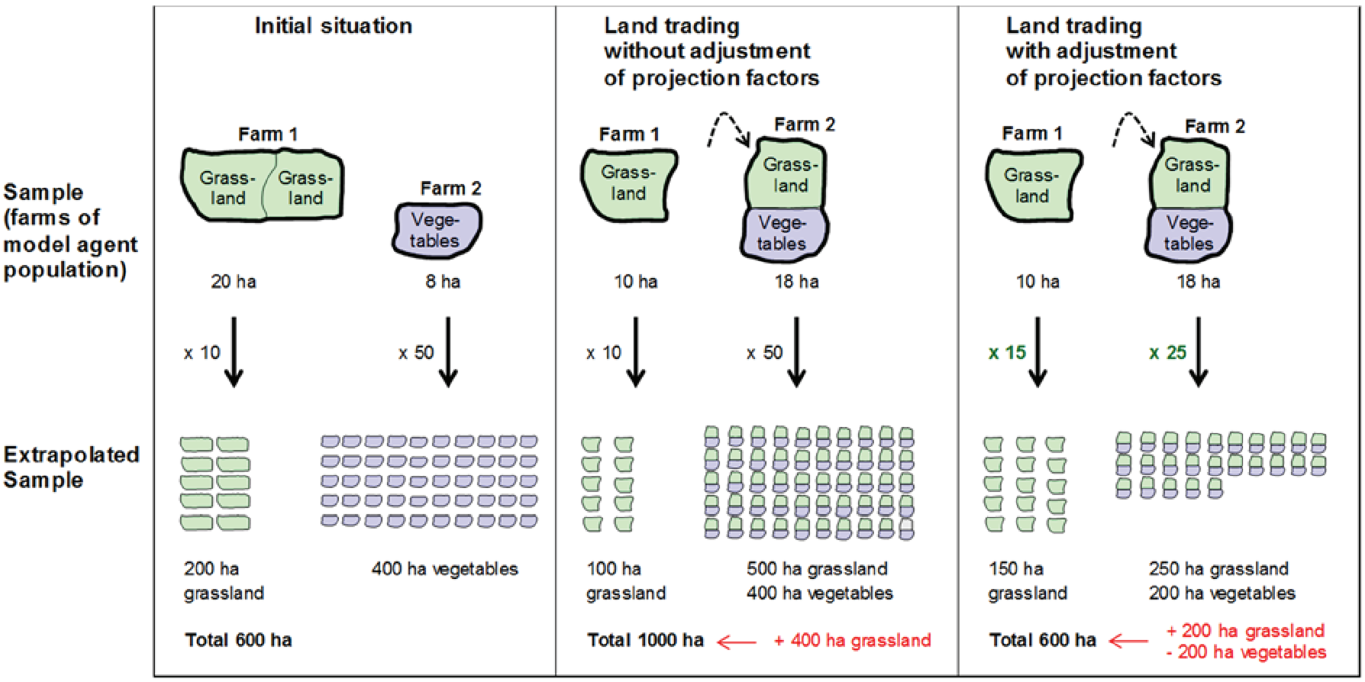

Figure 3.6: Aggregation errors of land trade with farm-specific extrapolation factors.

rent options are analysed has a positive influence on the reliability of the model results (see also Chapter 7). On the other hand, it must be conceded that methods that have worked well in the past will not necessarily work well in future.

As is probably true of most FADN networks, the Swiss FADN does not constitute a fully representative sample of Swiss agriculture – a fact that should always be borne in mind when it is used as the main data source for a forecasting model. The SWISSland model has been shown to yield the best results when permitted to use a certain group of farms more than other groups. An adjustment of the sample by the multiplication of under-represented farms and if necessary the removal of over-represented ones showed a better alignment with the observed trends, and prevents inconsistencies arising from relationships between farm agents assigned different extrapolation factors. On the other hand, an optimisation of individual-farm extrapolation factors could help to enhance alignment with the population as a whole. Furthermore, research is needed to determine which method would be the most appropriate in cases of greater changes in economic or political conditions within the time period under consideration. As every model differs in terms of its structure, underlying data and objectives, the most suitable method for extrapolation to the sector must probably be determined separately for each model. The sensitivity of the model to the aggregation approach as well as the lack of any clear "winner" in terms of which approach should be taken suggests that "agent-based models with aggregated agents" is either a fundamentally flawed concept (since e.g. individual-agent interactions such as land exchange are problematic to represent), or at the very least an area requiring a vast amount of work.

4 The SWISSland Market Model Architecture

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4.1 Overview of the market model

This study uses an applied recursive partial-equilibrium, multiple-commodity model of agricultural policy. The SWISSland market model is a reduced-form model that captures the economic behaviour of producers, consumers and trade. It includes variables for crop production and livestock activities, consumption, exports, imports, stocks, world prices, and domestic producer and consumer prices. Commodity-based markets are modelled such that quantities and prices clear the market (Hamilton, 1994). Thirty-six commodities are included (wheat, maize, other coarse grains, soybeans, sunflower seed, rapeseed, sugar, soybean oil and meal, sunflower-seed oil and meal, rapeseed oil and meal, beef and veal, pork, poultry, raw milk, butter, five types of cheese, non-fat milk powder, full-fat milk powder, liquid milk, and other dairy products). All commodities are treated as tradable, except for raw and liquid milk. The mode, which will be based on the "homogeneous product" assumption. The model is a reduced-form model with production, consumption, and other behavioural equations specified by constant-elasticity functions. The core set of policies includes specific import and export taxes/subsidies, tariff-rate quotas (TRQs), and producer and consumer subsidies.

The innovative and flexible design of the SWISSland market model enables users to analyse a variety of domestic and trade-policy issues. The model is written in GAMS (General Algebraic Modelling System) using PATH, a Mixed Complementarity Problem (MCP) solver. MCP also allows for endogenous determination of active regimes and the consequences of regime shifts, such as the shift from an "in-quota" to an "over-quota" tariff: for example, the SWISSland Market model endogenously determines TRQ price and quantity.

4.2 Behavioural equations for supply

Crop production

Crop production PRD_{it} of crop *i* and year *t* is a function of production as well as the crop's own producer price and producer prices of other crops, which may be complementary or competing for acreage as follows:

$$PRDC_{it} = Conscrp_{it} * PRD_{it-1}{}^{\lambda_i} \prod_{i.i.} P\,\mathrm{Pr}_{ijt}{}^{\sigma_{ij}} \quad \text{for i} \in \text{crops}, \tag{4-1}$$

where *Conscrpit* is a measure that captures the past interaction between producer price and crop production, PRD_{it-1} is lagged area of crop i, λ_i is a partial adjustment parameter, $P\,\mathrm{Pr}_{ijt}$ is own producer price i and producer prices of other crops j, and σ_{ij} cross-price elasticities for crop production.

Processing model for oilseeds

Processing demand for three oilseeds, $Crush_{it}$, is specified as a function of lagged demand processing, $Crush_{it-1}$, and crush margins MGp_{it}, as follows:

$$Crush_{it} = Conscru_{it} * Crush^{\lambda_i}{}_{it-1} \prod_{\text{j oilseeds}} \mathrm{MGp}_{it}{}^{\sigma_{ij}} \tag{4-2}$$

where i depicts oilseed category, t indicates time, and $Conscru_{it}$ is a measure that captures the past interaction between the crush margin and crushing. In this specification, the demand for processing increases along with increases in the processing/crushing margins, and vice versa. In other words, as the processing margin increases, there will be a greater demand for oilseeds for processing, resulting in a gradual rise in oilseeds prices. σ_{ij} is the crush elasticity with respect to own price i and cross-price j of oilseeds, whilst is λ_i a partial adjustment parameter. The crushing margin MGp_{it} is specified as a function of the extraction rate of crush products, the prices of crush products (meal and oil), and the consumer prices for oilseeds.

Processing supply is defined as processing demand multiplied by the respective extraction factor. Production of oilseed products i at year t (PRD_{it}) is determined by the quantity of i^{th} oilseed crushed and by an exogenous extraction rate as follows:

$$PRD_{it} = Crush_{it} * Extrate_{it}\ , for\ i\ \epsilon\ oilseed\ products \tag{4-3}$$

where $Crush_{it}$ is the crush of the associated oilseed and $Extrate_{it}$ is the extraction rate, assuming a fixed-proportion meal-and-oil-production technology.

Livestock production

Production of livestock product i at year t, PRD_{it}, is a function of its own producer price and the producer prices of the other livestock products, a feed-cost index for that product, and production of that product in the previous year as:

$$PRDT_{it} = Const_{it} * PRD_{it-1}{}^{\lambda_i} \prod_{\text{j livestock}} P\,\mathrm{Pr}_{ijt}{}^{\sigma_{ij}}\ FECOST_{it}{}^{\eta_i} \tag{4-4}$$

where $Const_{it}$ is a measure that captures the past interaction between the producer price and feed costs and production, PRD_{it-1} is the production of i_{th} livestock product in the previous year, λ_i is a partial adjustment parameter, $P\,\mathrm{Pr}_{ijt}$ is the producer price of i livestock products (own) and the producer prices of other livestock products j (cross-price),

σ_{ij} is the price elasticity of production, $FECOST_{it}$ is the feed-cost index for each livestock product i, and η_i is the elasticity of production with respect to input prices. The feed-cost index $FECOST_{it}$ is a function of feed use and feed prices. There are nine commodities in the model that can potentially be used as livestock feed: wheat, maize, other coarse grains, and all meals (soybean, sunflower-seed, and rapeseed by-products).

Feed demand

The feed demand for livestock, $FEEDL_{ikt}$, is specified as a function of livestock production PRD_{kt}, feed-demand coefficient $FEED_{ikt}$, and feed prices FP_{it} as follows:

$$FEEDL_{ikt} = Const_{ikt} * PRD_{kt} * FEED_{ikt} \prod_{i \in feed} FP_{it}^{\sigma_{ijk}} \quad \textbf{(4-5)}$$

where i depicts feed category, k depicts livestock/meat category, t indicates year, $Const_{ikt}$ is a measure that captures the interaction between feed price and feed demand, $PRDT_{kt}$ depicts production of livestock/meat, and $FEED_{ikt}$ indicates feed used by livestock/meat category. Feed prices are depicted as FP_{it}, while σ_{ijk} is the own feed-price elasticity of demand for $i=j$ and the cross-price elasticity of feed demand for $i \neq j$ for meat and milk k.

Processing model for dairy products

As mentioned earlier, the model identifies 11 dairy products (Figure 4.1). The "other dairy products" aggregate includes ice cream, yogurt and whey. Dairy products are processed from raw milk as livestock products in the model. Production of dairy products i at year t is modelled as proportional to both the total quantity of raw milk processed $PROC_{'\text{Processed milk}',t}$ and the price of dairy products. With this specification, a change in the price of one processed dairy product relative to another leads to changes in the mix of processed dairy products made from raw processed milk. The equation is as follows:

$$\frac{PRD_{it}}{PROC_{'\text{Processed milk}',t}} = Consdai_{'i,t} * \left(\frac{PRD_{it-1}}{PROC_{'\text{Processed milk}',t-1}} \right)^{\lambda_i} \prod_{j \in \text{dairyproducts}} P\,\Pr_{ijt}^{\;\sigma_{ij}} \quad \textbf{(4-6)}$$

where PRD_{it} is production of the i_{th} dairy product at year t, $PROC_{'\text{Processed milk}',t}$ is total production of raw processed milk, and $\frac{PRD_i}{PROC_{'\text{Processed milk}',t}}$ is the proportionality, which indicates that the production of the i_{th} dairy product varies in direct proportion to the total production of raw processed milk and the proportionality lagged one year. $P\,\Pr_{ijt}$ is the producer price of dairy products I and j, $Consdai_{'i,t}$ is a technology parameter that determines the production of dairy products over time, λ_i represents the rate of adjustment, and σ_{ij} is the own and cross-price elasticity of supply for dairy products.

Demand for dairy products

Raw-milk processing demand $PROC_{it}$ for j dairy products such as liquid milk, cheese, butter, nonfat milk powder, full-fat milk powder and other dairy products, is specified as a function of lagged raw-milk demand $PROC_{it-1}$ and the ratio of the value of the processed dairy product to the value of raw milk used (needed) in processing:

$$PROC_{it} = Consproc_{it} * PROC_{it-1}^{\lambda i} \left(\sum_j PRD_{jt} P\,\Pr_{jt} \right)^{\sigma i} \quad \textbf{(4-7)}$$

where i indicates raw milk, j indicates processed dairy products, t depicts time, and $Consproc_{it}$ is a measure that captures the past interaction between processed dairy products and the demand for raw milk to be processed. $P\,\Pr_{jt}$ is the producer price of processed dairy products (j = liquid milk, five types of cheese, butter, non-fat milk powder, etc.), λ_i is the partial adjustment parameter, and σ_i is the price elasticity of demand for raw milk in the processing of dairy products. In this specification, PRD_{jt} depicts (over time t) the demand for dairy products, whilst $PROC_{it}$ depicts the demand for raw milk for processing.

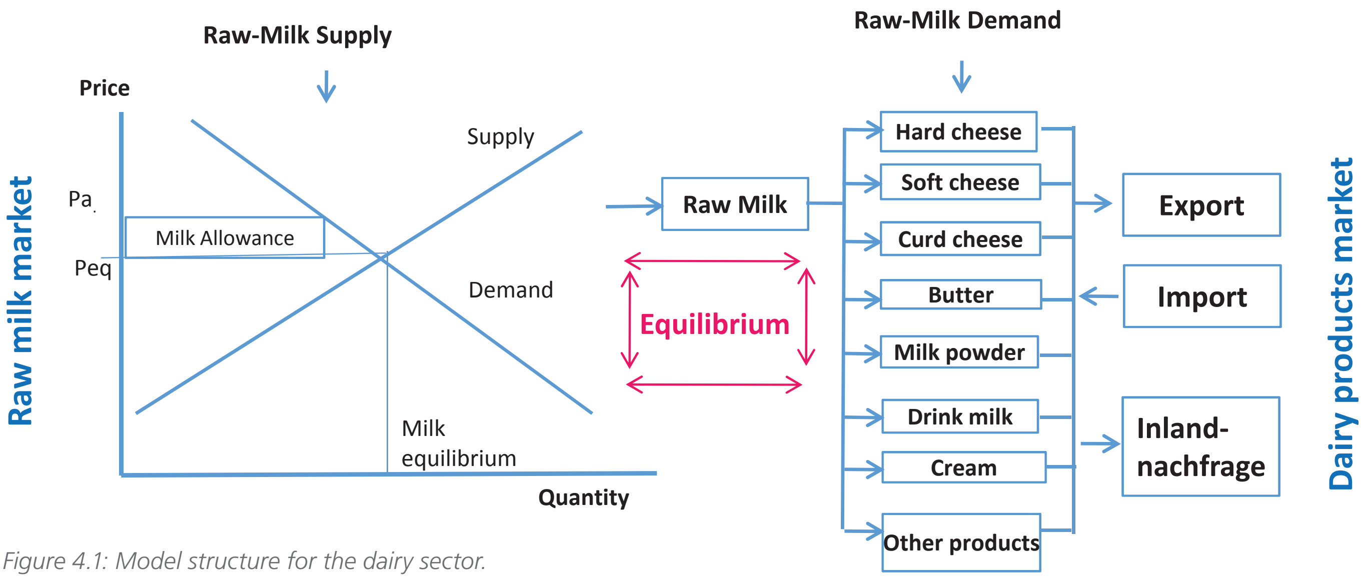

Figure 4.1: Model structure for the dairy sector.

4.3 Behavioural equations for food demand

Food demand exists for all commodities in the model except for raw milk and the three oilseed meals. Food demand is specified as per capita and aggregate. Per-capita food demand $FOODpc_{it}$ for commodity i at year t is a function of consumer price $PC_{i,t}$ and per-capita income in real terms $RGDpc_t$, as follows:

$$FOODpc_{it} = Consfo_{it} \prod_{i \in food} PC_{i,t}{}^{\sigma_{ij}} \, \mathrm{RGDpc}_t^{\varepsilon_i} \quad \text{for } i \in \text{food}, \tag{4-8}$$

where $Consfo_{it}$ is a measure that captures the interaction between consumer price, per-capita demand, and per-capita income, σ_{ij} is the own- and cross-price elasticity of demand, and ε_i denotes the income elasticity of food demand for commodity i at year t. Aggregate food demand for all commodities, $FOOD_{it}$, is specified as a function of per-capita commodity demand and population:

$$FOOD_{it} = FOODpc_{it} * POP_t \tag{4-9}$$

where $FOODpc_{it}$ is per-capita food demand and POP_t denotes the Swiss population at year t. The demand-elasticity systems used in this model are synthetic in the sense that they are not estimated as systems, but as individual elasticities stemming from various sources.

4.4 Endogenous tariffs under tariff-rate quotas

Tariff-rate quotas (TRQs) can also alter the relationship between world and domestic prices in the model (Morath and Sheldon, 1999; Skully, 2001). In-quota and over-quota tariffs for TRQ commodities are treated explicitly with a discontinuity in the tariff rate at the threshold where the quota amount is reached.

There are three possible regimes for a TRQ commodity (Figure 4.2):

a) Imports are below the quota level: In this case, the ratio between world and domestic prices still holds, with the relevant tariff being the in-quota tariff.
b) Imports are exactly equal to the quota. This occurs if the quota is filled but the over- quota tariff is high enough to prevent additional imports. The domestic price cannot be determined directly from the world price and the tariffs in this case, since there is a range of autonomy regarding the domestic price. The difference between the domestic price and the world price plus the over-quota tariff is commonly referred to as "water" in the over-quota tariff.
c) Imports are above the quota level: In this case, the relationship between world and domestic prices also holds, with the relevant tariff being the over-quota tariff.

If a TRQ commodity falls under regime c, the model endogenously determines the domestic price based on the quota, domestic demand, domestic supply, and exports. The model also endogenously determines the regime under which a TRQ commodity falls, so that the regime can change depending on the scenario being analysed. The producer price is linked to the market price by an exogenous marketing margin. For tradables, the "market clearing" condition requires net exports to equal zero, whilst domestic markets must clear for non-tradables.

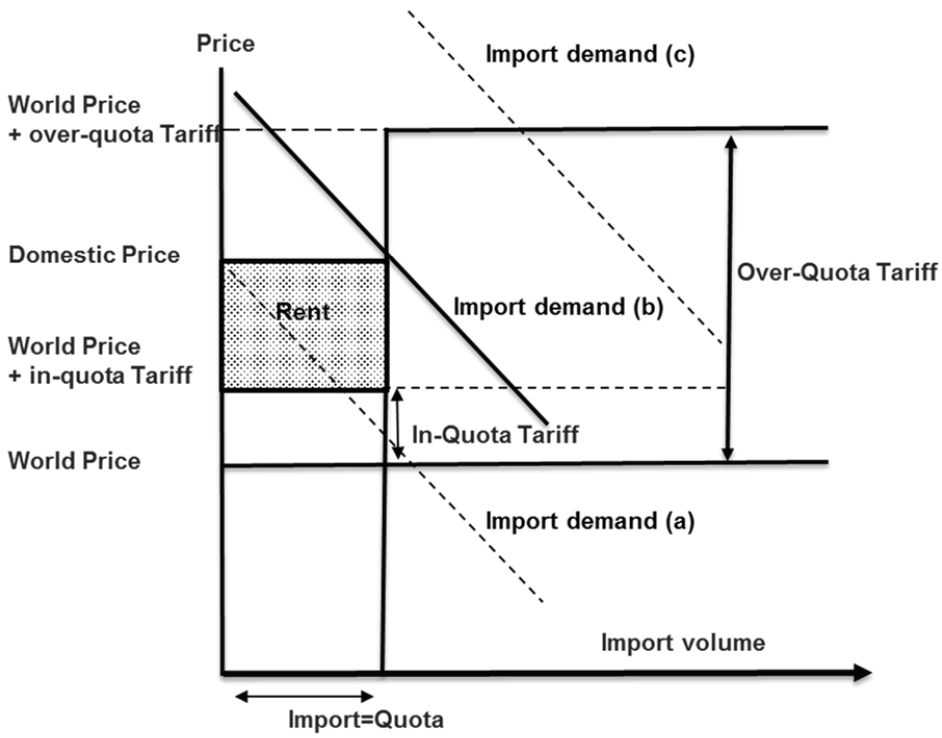

Figure 4.2: Modelling tariff-rate quotas.

4.5 Price mechanism and transmission

Domestic prices

Domestic prices are endogenously determined in the model. Import prices are in euro, and all domestic prices and policies are expressed in the local currency, the Swiss franc. Real exchange rates are treated as exogenous. Domestic prices for all traded commodities (except for raw milk and liquid milk) depend on world prices, exchange rates, transport costs, and country-specific policies that affect prices. Domestic prices $DOMP_{it}$ are specified as a function of import prices adjusted for an ad valorem tariff (i.e. first-tier or in-quota rate $TM_{it,in}$ and second-tier or over-quota rate $TM_{it,out}$) and transport costs $Transc_{i,t}$ as follows:

$$DOMP_{it} = PIM_{it} * ER_t * (1 + Tm_{it,in} + z_{it} * Tm_{it,out}) + Transc_{i,t} \quad \textbf{(4-10)}$$

where PIM_{it} denotes the import price of commodity i at time t, whilst z_{it} relates to the TRQ. The variableis z_{it} bounded by values ranging from 0 to 1 [0,1] and solves endogenously for the level on which the quota operates. To model a TRQ directly, we use the complementarity MCP formulation to capture this switching from one regime to another. There are two issues in modelling TRQs: how to model a switch from one regime to another, and how to handle the boundary case where imports are exactly at the quota limit. In the latter case, we have a range of possible supply prices whose bounds are determined by the below- and above-quota tariffs. The model determines a supply price in this range such that markets clear. If the quota is not binding, it takes the value of 0; otherwise, it takes the value between 0 and 1. TRQs are specified as functions and are solved explicitly in the model, taking account of the discontinuity in the tariff rate using the MCP formulation.

The domestic prices for non-tradable commodities (raw milk, liquid milk) are either determined by domestic supply-demand equilibria, or the material balance equation holds:

$$NET_{it} = PRD_{it} - CON_{it} + \Delta EST_{it} \quad \textbf{(4-11)}$$

where i denotes non-traded commodity, and t year. PRD_{it} is production, ΔEST_{it} is variation of stocks at year t, and CON_{it} is consumption.

Producer prices

Producer prices ($P\Pr_{jt}$) are specified as a function of domestic prices adjusted by an exogenous marketing margin, $Pmrg_{it}$. The fixed-margin factor is defined as the ratio of observed producer prices to domestic price:

$$P\Pr_{it} = DOMP_{it} * \text{Pmrg}_{it} \quad \textbf{(4-12)}$$

where $P\Pr_{jt}$ is producer prices, $DOMP_{it}$ is the domestic price, and $Pmrg_{it}$ is the fixed margin.

Consumer prices

Consumer prices PC_{it} for commodity *i* at time *t* are specified as a function of domestic prices adjusted by a fixed-factor margin $PCmrg_{it}$ covering transport, processing and all other marketing costs:

$$PC_{it} = DOMP_{it} * \text{PCmrg}_{it} \quad \textbf{(4-13)}$$

4.6 Trade and model closure

The model balances supply and demand for each tradable commodity i at time t as follows:

$$NET_{it} = PRD_{it} - CON_{it} + \Delta EST_{it} \quad \textbf{(4-14)}$$

where PRD_{it} is production, CON_{it} is total consumption of food and feed, and ΔEST_{it} is variation in stocks. The markets for each tradable commodity are governed by market-clearing conditions. For any tradable commodity i and time t, one of the export/import pairs is specified as "relatively free" to allow the market to clear. In the description below, we consider the case in which import quantities are determined as a function of import price, and exports float to clear the market. The case where the roles are reversed is treated similarly.

Owing to various cross-price relationships on both the demand and supply sides, a change in the net trade position of any product may cause a change in the net trade position of any other product.

4.7 Data used and calibration of the model

Data were obtained from various sources, including the Swiss Federal Office for Agriculture (FOAG), the Swiss Federal Statistical Office, the Swiss Farmers Association, and others (Proviande). The base year data are the mean of the last three years. Base data for crops (area, yield, production, consumption, stocks, and trade) are drawn from Swiss Farmers' Association data, including from the production, supply, and demand database.

Parameters in the model stem from various sources, including the Swiss Meat Market (Schluep Campo, 2004), Koch and Rieder (2002), the Food and Agricultural Policy Simulator (FAPSIM) (Gadsen *et al.*, 1982), the CAPRI model, and the OECD Aglink model (Conforti and Londero, 2001). Adjustments and restrictions are imposed on elasticities to satisfy theoretical requirements such as symmetry and homogeneity in output supply equations, food/consumer demand equations, feed demand equations, and harvested acreage equations. Export and import data are available from the Swiss Federal Customs Administration. The projected world market prices for the agricultural products examined are based on DG-AGRI Agricultural Outlook and FAPRI World Agricultural Outlook.

The macroeconomic variables of income, population and real exchange rate are incorporated in the model as exogenous parameters. The model is also partial in the sense that the international environment is exogenous and consists of given import and export prices for each product, the distance between them being the Cif-fob spread. Import and export prices are determined exogenously, since Switzerland can be considered to be a small country with no significant impact on world market prices.

5 The Green Side of SWISSland

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5.1 Benefits of considering ecological aspects in agent-based models

Agriculture contributes to various environmental impacts (Table 5.1). For some of these impacts, such as biodiversity, pesticide pollution and soil erosion, agriculture is the main factor responsible. For others, such as greenhouse gases and emissions of medicinal products, the percentage of effects deriving from agriculture is low compared to that stemming from industry, services, transport or households. Nitrogen emissions are especially important, since they are the main factor responsible for various environmental impacts; however, they are difficult to deal with, since a reduction may lead to a shift to subsequent production processes or different nitrogen forms.

Table 5.1: Environmental spheres influenced by the agriculture sector

Environmental Spheres	Environmental Aspects for which Swiss Legislation defines Objectives
Biodiversity and landscape	Biodiversity
	Landscape
	Space for watercourses
Climate and air	Greenhouse gases
	Nitrogenous air pollutants (ammonia, nitrogen oxides)
	Diesel soot particles
Water	Nitrate
	Phosphorus
	Plant-protection products
	Medicinal products
Soil	Pollutants in soil
	Soil erosion
	Soil compaction

Source: FOEN and FOAG, 2008

One of the main purposes of most agricultural agent-based models is to evaluate policy measures. Such measures are often justified by market failures associated with public goods and externalities, in most cases ecological aspects. Considering these aspects within the model allows us to analyse the impacts of the measures not just on the production quantities and economic results, but also on the parameters at which the measures are aimed. Furthermore, agent-based models are able to take into account the heterogeneity of the agents, which is often important in terms of ecological performance as well as in economic terms. A life-cycle assessment study of 68 Swiss dairy farms, for example, revealed a factor of 6 between the farm with the lowest global-warming potential per kg milk and the one with the highest value (Hersener *et al.*, 2011). Taking account of ecological aspects within the model requires the agents to be able to respond to policy measures, and thus to influence the environmental impacts of the latter.

The following chapters describe different ways of expanding the SWISSland agro-economic agent-based model with ecological attributes. Certain environmental indicators can be derived from the economic data (Chapter 5.2). Important environmental values may be formulated within the model (5.3). A link with existing environmental models could provide a wide range of environmental data (5.4). The most suitable method depends on the subject and aim of the specific analysis. Perhaps the simultaneous use of more than one method will lead to the most beneficial results.

5.2 Environmental indicators within basic data

Agricultural production is strongly associated with nature. Various processes are combined with externalities having either a positive or negative influence on environmental goods. Certain policy measures aim to improve environmental goods by bearing in mind these connections. Furthermore, indirect impacts must be allocated to these products by providing the means of production used. Since most of these activities and measures are directly associated with costs, revenues or direct payments, a proportion of FADN data provides information on environmental aspects (Table 5.2).

Delivered with the basic agent data, environmental indicators can be reported in the model results without extra work. Since these indicators are part of the model entities, their values are directly affected by the reaction of the agents to model calculations with different scenario assumptions. Included in model restrictions or in the objective function, the indicators may also form part of the changing assumptions. They do not give a precise indication of the real environmental impacts, however. In order to obtain differentiated results, the relationships between the model values and the environmental figures must be taken into account either directly within the model or via a connection with appropriate environmental models.

Table 5.2: Environmental indicators in accountancy data		
FADN Value		**Indicator for:**
Costs	Pesticides	Toxicity (soil, water, air, human)
	Fertilisers	Potential for nitrogen and phosphorus emissions, exhaustion of phosphorus resources
	Concentrates	Potential for nutrient surpluses, demand for land area, other indirect impacts
	Energy (fuels, electricity)	Exhaustion of resources, greenhouse-gas emissions
	Machine costs	Use of resources and energy
	Building costs	Use of resources and energy
Revenues	Product revenues	Efficiency of production (revenues in relation to costs)
	Specific environmental measures (maintenance of public green spaces, biogas production, etc.)	Biodiversity, exhaustion of resources
Direct payments	Biodiversity subsidies - Ecological compensation areas - Extensive or low-intensity use of grassland	Biodiversity, prevention of nutrient emissions
	Subsidies for production systems - Organic farming - Low-intensity arable farming - Grassland-based cattle husbandry	Environmentally sound production, prevention of emissions
	Subsidies for the efficient use of resources - Low-emission manure application - Low-emission pesticide application - Low-impact soil cultivation	Prevention of emissions, soil fertility, biodiversity
Farm characteristics	LU per ha land	Potential for nitrogen and phosphorus emissions
	Organic production	Environmentally sound production

5.3 Modelling environmental figures in SWISSland

Nitrogen is a key element in both agricultural production and the environmental performance of agriculture. Due to the complexity of the nitrogen cycles, man-made and natural inputs into the agricultural system substantially exceed the outputs with the harvest products. Nitrogen surpluses often have environmental impacts. Nitrogen not absorbed by plants or animals normally results in ammonia and nitrous oxide emissions as well as nitrate leaching. These compounds diminish water, soil and air quality, contribute to the greenhouse effect, and reduce biodiversity through the eutrophication of natural ecosystems. Allowing for scarcely avoidable losses, the cross-compliance scheme – introduced in Switzerland in the 1990's – requires a finely tuned nitrogen balance called Suisse balance. Although this scheme has had some success in reducing the surpluses, at an average of around 108 kg nitrogen per hectare, these are still significant. For this reason, other policy options such as economic incentives must be considered. A nitrogen balance was introduced in order to evaluate such options in SWISSland.

Basically, there are two different types of nitrogen balance at farm scale: farm gate and soil surface balance (Oenema *et al.*, 2003). In a farm-gate balance, all of a farm's nitrogen inputs and outputs are measured, whilst a soil-surface balance measures nitrogen inputs in the soil and nitrogen content of the harvest. Suisse balance represents a modified version of the latter. Although manure inputs in the soil are taken into account, neither the losses from manure – mainly in the form of ammonia – nor certain further inputs such as nitrogen deposition are assessed.

Two kinds of nitrogen balance must be integrated into the SWISSland model. The first, the Suisse balance, must be incorporated as a model constraint (Equation 5.1). Manure nitrogen content (FarmyardmanureN) and plant nitrogen demand (NeedplantsN) were estimated according to Flisch *et al.* (2009). The N-input by fertiliser (FertiliserN) is estimated by fertiliser cost per area and fertiliser recommendations. The Suisse balance instructions permit an exceedance of manure and fertiliser N inputs equivalent to 10% of crop requirements. To account for the uncertainties of different manure types, the N-content of the manure of the individual SWISSland agents was varied by a correction factor, under the assumption that all farms meet Suisse balance requirements in the first year – a fairly safe assumption, since this is a precondition for receiving direct payments. In addition to the Suisse balance instructions, manure and fertiliser application is modelled for the farm as a whole and in addition for the individual crops or plots.

$$\sum Farmyardma\ nureN + \sum Fertiliser\ N \le \sum Needplants\ N * 1.1 \quad (5\text{-}1)$$

$$SurplusN = \sum InputN - \sum OutputN \quad (5\text{-}2)$$

$$\sum InputN = \sum FertiliserN + \sum FeedN + \sum AnimalbuyN + \sum Deposition\ N + \sum FixationN \quad (5\text{-}3)$$

The second type of nitrogen balance – needed to evaluate the success of the measures – is a farm-gate balance (SurplusN), which is estimated for each agent (Equation 5.2). Nitrogen input into the farm consists of several components (Equation 5.3). Input from fertilisers (FertiliserN) for each field is estimated using the same methodology as in the Suisse balance. N-input from concentrates (FeedN) is estimated by feeding cost per animal and protein content, with animals purchased during the year being multiplied by their N-content per animal unit (AnimalbuyN). For inputs from deposition (DepositionN), standard values were chosen (Jan *et al.*, 2013). The fixation rate per hectare (FixationN) depends on crops and intensity (see Table 5.3). For pastures and meadows, values were estimated using the formula of Boller *et al.* (2003), with clover percentage being estimated according to common sowing mixtures and standard yield, and fertiliser application estimated according to Flisch *et al.* (2009). For soybeans and legumes, a fixation rate of 130 kg $ha^{-1}a^{-1}$ was assumed (Sorg, 2005; Salvagiotti *et al.*, 2008). For farm output (OutputN), Flisch *et al.* (2009) multiplied production quantity by standard values for nitrogen content. Where protein content alone was available, the mass ratio of proteins to N was assumed to be 6.25 (Janssen and Oenema, 2008). Individual-farm intensity levels for each crop were estimated on the basis of yield functions from the literature fitted to the initial fertiliser inputs and yields, in order to increase the agents' ability to respond to policy measures associated with nitrogen emissions. Nitrogen surplus is not yet divided into different flows or emissions. Modelling the paths of losses would require specific production parameters. At the same time, this would allow technical emission-reduction measures to be incorporated into the model. The estimation of emissions, however, is subject to significant uncertainties.

The inclusion of environmental figures in an economic agent-based model allows for a variety of applications, since not only does this offer the option of a subsequent calculation for an economically optimised model solution, but these dimensions can also be tied into the optimisation via the objective function, or as restrictions (see, for example, Zimmermann, 2008 or Schader, 2009). Even so, the formulation of these figures may require substantial effort, and in a linear model like SWISSland the relationships between variables are restricted to linear equations. Furthermore, the model and data must be updated regularly, or even reformulated whenever studies generate improved ecological models. Linking SWISSland to an existing ecological model instead of incorporating it into the model ensures that both models can be updated and extended independently.

5.4 Linking SWISSland with environmental models

A linkage of two models can be designed iteratively or hierarchically. With an iterative connection, the results of both models may influence one another to a certain degree. A hierarchical connection limits the flow of results obtained to a single direction. In the case of SWISSland, a hierarchical linkage would seem to be the more suitable choice, for a number of reasons. Firstly, most of the scenarios analysed using SWISSland involve changes in economic or policy conditions, so environmental outcomes are not usually addressed directly, but form part of the results; Secondly, SWISSland calculati-

Table 5.3: Estimated clover percentages and nitrogen fixation rates of different meadow and pasture types

	Percentage Clover (%)	Fixed N (kg $ha^{-1}a^{-1}$)
Temporary ley	10	72
Natural meadow	5	30
Less-intensive meadow	7	14
Extensive meadow	5	10
Natural pasture	5	14
Extensive pasture	5	14

ons are time-consuming: repeated interaction with another model would considerably increase the time needed; and finally, an interaction requires models to be able to react to the other models' results, which in the majority of cases would call for substantial extensions of the SWISSland model formulations. Despite this, the most important values influencing the environmental figures must also be known for the SWISSland results in a hierarchical linkage. The following sections describe two examples where SWISSland is linked with environmental models.

Linkage with a land-management model

Agricultural systems stand at the interface between the anthroposphere and natural ecosystems. Appropriate farmland management is crucial for the sustainable use of soil as a limited natural resource. Numerous boundary conditions, drivers and pressures must be taken into account in order to predict the impact of policy measures and management options on soil quality. With this in mind, we have assembled a combination of existing socioeconomic, regional-land-management and biophysical soil models (Figure 5.1). Various policy scenarios are analysed with SWISSland, for example a tax on fertiliser or fossil energies. The results, especially the optimised land use and animal population per farm, are applied to the land-management model. This model calculates fertilisation and crop rotation for each plot. Biophysical models then estimate nutrient and pollutant flows and balances.

Since this linkage analyses selected geographical regions with around 200 farms, the SWISSland database must be adapted to the region in question: the spatial structure of farms and plots is established on the basis of available GIS data. The actual crop areas and animal population per farm are derived from administrative data. By contrast, FADN data is available from only a small proportion of farms within a region, so the economic figures are estimated on the basis of FADN data from similar farms. For each farm of the study region, the best-fitting FADN farm, i.e. the one for which the squared deviations associated with important attributes are minimal (equation 5.4), is identified. These attributes must be contained in both databases. Around 40 attributes were selected: Crop-area and livestock-number categories, age of farmer, percentage of hired workforce, farming system (e.g. organic), production zone (valley, hill or mountain), and milk yield per cow. In the equation, attributes are normalised by their standard deviation or range, and weighted by an assigned importance. For example, a high importance was assigned to the number of livestock units per hectare of farmland. For each farm in the study region, the required economic values were then adopted from the selected FADN farm. This procedure does not identify the real values, but rather those which probably come close to the real values for most of the farms.

$$MD_s = Min_{(f=1...F)} \sum_a \left(\left(\frac{A_{af} - A_{as}}{SD_a} \right)^2 * W_a \right) \qquad \textbf{(5-4)}$$

A_{as} Value of attribute *a* on study-region farm *s*
A_{af} Value of attribute *a* on FADN farm *f*
SD_a Standard deviation of attribute *a* in sample of study-region farm
W_a Weight of attribute *a* in the allocation process
MD_s Minimal weighted deviation of attributes *a* between study-region farm *s* and FADN farms *f*

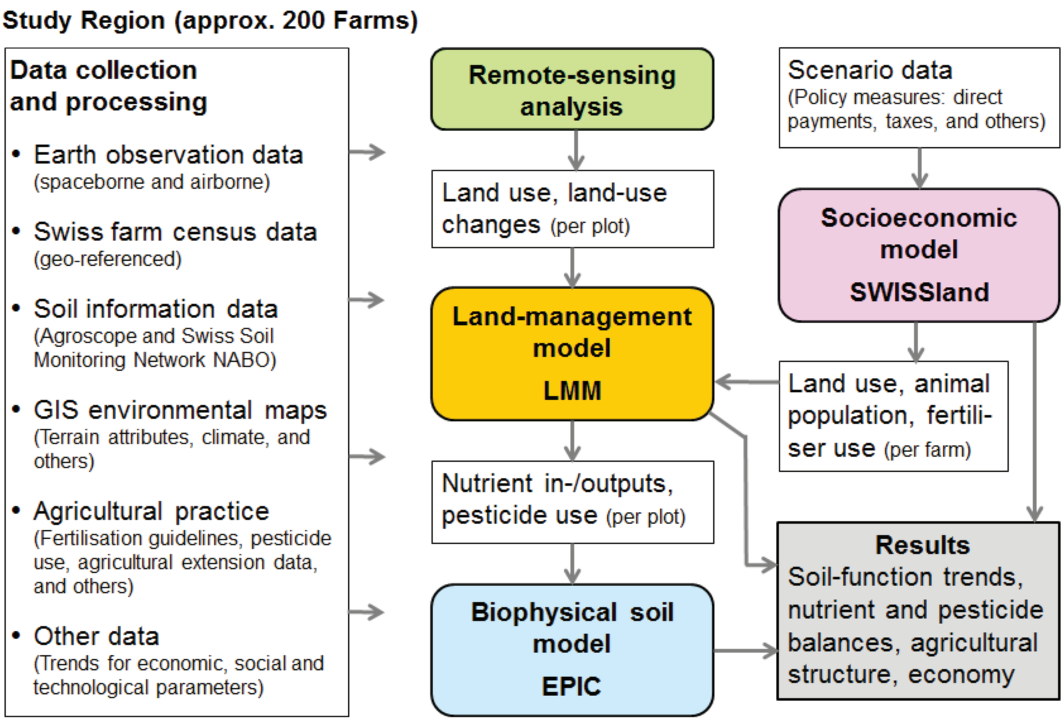

Figure 5.1: Linkage of SWISSland with a land-management model: integrated modelling framework.

This integrated modelling framework, which is currently applied in the Swiss National Science Foundation's "Soil" research programme, generates more supplementary knowledge than do the individual models. Its main outcomes are the detection of medium-to-long-term changes in soil functions resulting from socioeconomic trends, assessment of the sustainability of different agricultural soil-management strategies, and the identification of indicators for sustainable soil-management practices.

Linkage with a life-cycle assessment tool

Agricultural production impacts the environmental compartments of air and water, in addition to soil. Moreover, indirect impacts through provision of the means of production must be borne in mind. Life-cycle assessment (LCA) is a method that attempts to take all of the above impacts into account (ISO 2006a and 2006b). According to these standards, an LCA is divided into four phases (Figure 5.2). In the first of these, the definition of goal and scope sets out the context of the study, especially the boundaries of the system analysed and the functional unit describing the research topic to which the results refer. The inventory analysis records the flows between the system and nature, i.e. resource use and pollutant emissions. The third phase evaluates the impacts of the inventory results on the environmental problems examined. This impact assessment is divided into several steps, of which aggregation of the impact categories is optional. The final interpretive phase identifies significant results and presents conclusions, limitations and recommendations.

In order to estimate the environmental impacts of different policy scenarios, the SWISSland results can be transferred to an LCA tool (Figure 5.3). This tool represents a general farm system whose crop areas and livestock numbers as well as certain production specifications are modelled as variables. The system boundary is at the farm gate, i.e. the processing of the agricultural products is not borne in mind. By contrast, the impacts occurring as part of the provision of the means of production are taken into account. Since much of the quantitative data required for the LCA analysis, e.g. types and quantities of fertilisers or machinery used, is not contained in economic models, the mainly economic results must be extended by estimated process data, using either the economic values or the characteristic process parameters available in statistical data (Zimmermann *et al.*, 2011). This estimation reduces the heterogeneity of the LCA input data to a certain extent, so rather than calculating the environmental impacts for each SWISSland agent, which would take a long time, we first merge the model results into average farm types, or even into a single average farm.

The resultant environmental impacts must be correlated with the functional unit, normally the amount of food energy produced or the agricultural area. When different scenarios are compared, changes in the quantity and composition of production which could lead to changes in imports and exports must be taken into account. The combination of the agent-based model SWISSland with an LCA tool forms the basis for a sustainability assessment. Economic and social indicators such as income, income distribution or working hours are reported together with ecological impacts. Compared with the use of the individual models alone, a wider range of application and an improvement in the quality of the conclusions can be achieved. The type of connection chosen ensures that the models can be updated and developed independently of one other.

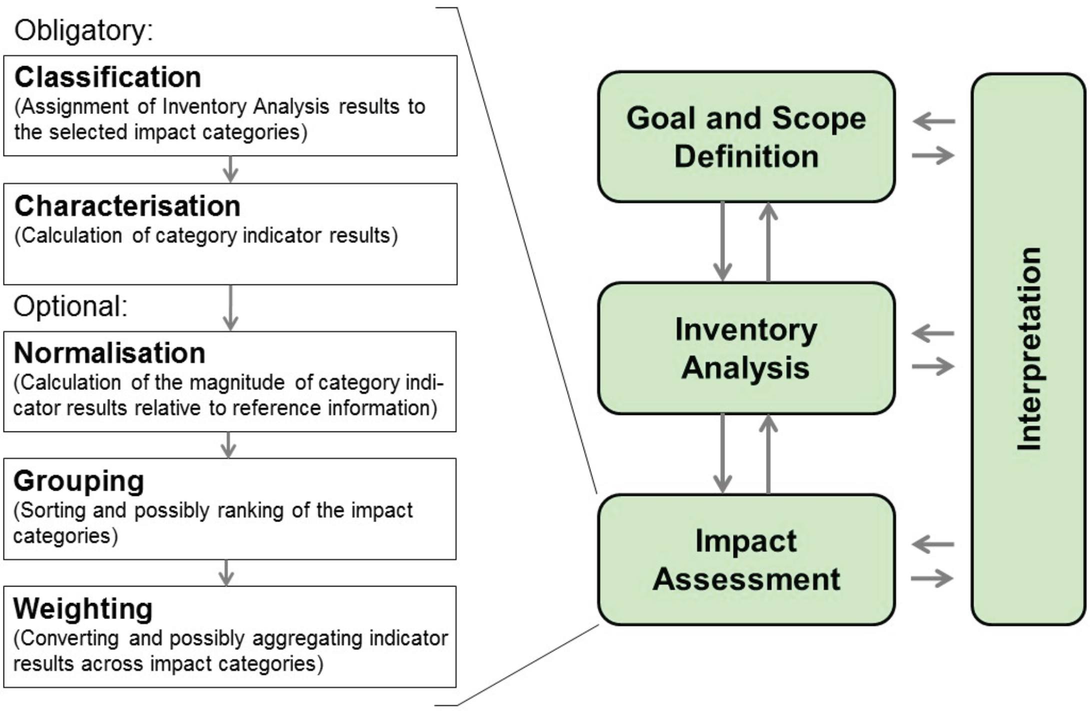

Figure 5.2: Life-Cycle Assessment (LCA) framework according to ISO Standards 14040 and 14044.

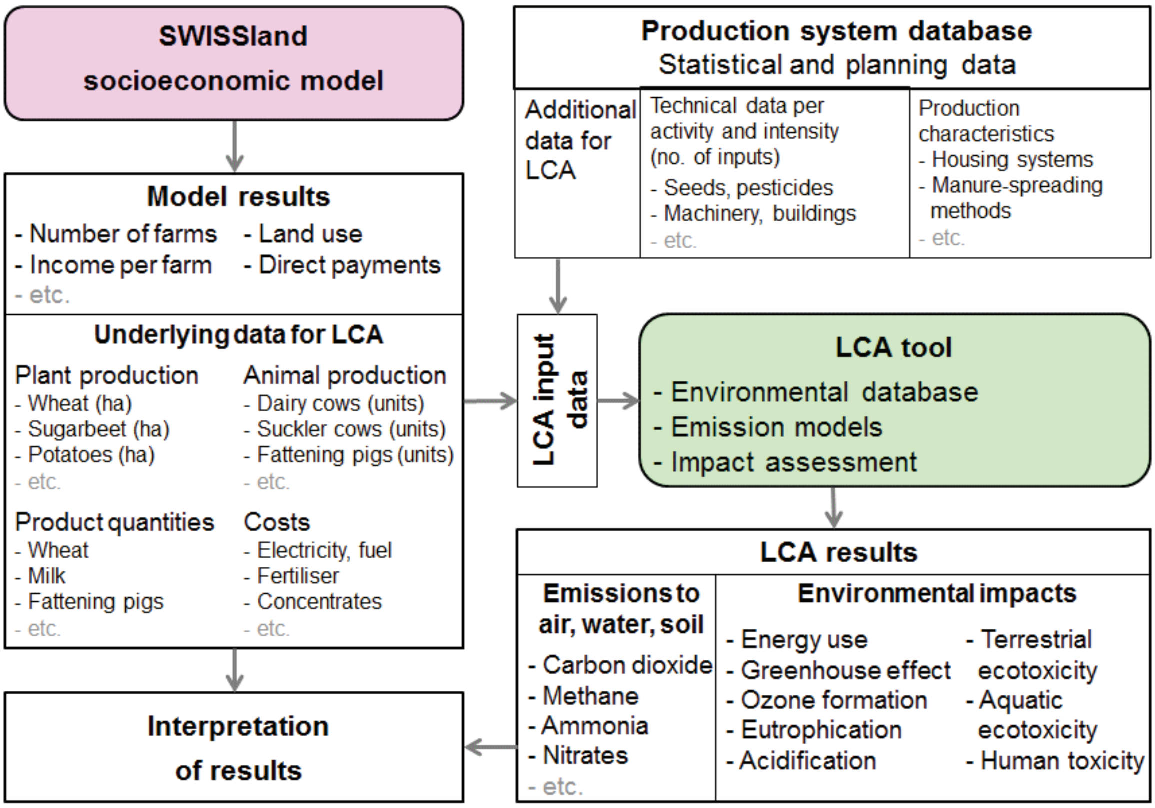

Figure 5.3: Link between SWISSland and LCA tool.

6 Technical Implementation

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6.1 Linking demand and supply

Market prices are calculated as a function of the year-by-year supply and demand for each product. The agents' supply module is therefore linked with the demand module in a two-step procedure (Fig. 6.1). In the first step, the supply of the 3000 agents is extrapolated to sectoral scale, as described in Chapter 3. In the second step, the prices for the current year are estimated based on the extrapolated supply and the demand functions described in Chapter 4. The market prices of the current year represent the agents' price expectations for determining the production decisions in the following year. Since the partial equilibrium model forecasts relative changes over the years, the supply and demand modules are linked on the basis of relative changes. To prevent supply and price fluctuations over the years that are mainly technically driven, the procedure illustrated in Figure 6.1 is repeated twice yearly and supply, demand and price averages over the two model runs are displayed. Said price averages represent the price expectations for the following year's production decisions.

The products of the supply module are linked to those of the demand module, as shown in Table 6.1:

6.2 Software and hardware solutions

We use the agent-based simulation software "Repast Simphony" as a framework for agent simulation. "Repast" is an extension of "Eclipse", a programming environment used for Java programming, and executes the single-farm optimisation models for which the software "GAMS" (=General Algebraic Modelling System) is used in combination with the solver "CPLEX". Based on Repast, entire simulation runs characterised by a defined set of procedures running consecutively within a period of one year could be executed, starting with the procedures of the supply module, continuing with those of the demand module, proceeding to the farm-exit and take-over modules, and finally progressing to the land-leasing module. In the supply module, we solve the 3400 single-farm optimisation models, around 500 of which – the agents of eight municipalities – are always solved in parallel. In the land-leasing module, we also solve the single-farm optimisation models of the land-leasing agents of between eight and 32 municipalities in parallel. A simulation run could be repeated over a period of several years. Lastly, Repast manages data exchange between the GAMS-file-based simulation modules and the database software MySQL. The MySQL database saves the model results of each simulation run (e.g. accounting data, group-formation data for forming population clusters, etc.) and provides the input data for the single-farm optimisation models. We use Excel to process the input data and import the Excel files into the database. Model results are exported from the database software using Excel and GAMS.

Table 6.1: Linking the products of the supply and demand modules

Bread cereals	Cereals
Fodder crop	Barley
Grain maize	Grain maize
Rapeseed	Rapeseed oil; rapeseed cake
Sunflower seed	Sunflower oil
Soya beans	Soya oil; soya cake
Sugar beet	Sugar
Potatoes	Potatoes
Milk	Raw milk, cheese, butter, cream, milk powder
Beef from suckler cows, fattening bulls, dairy cows and calves	Beef
Pork	Pork
Poultry	Poultry

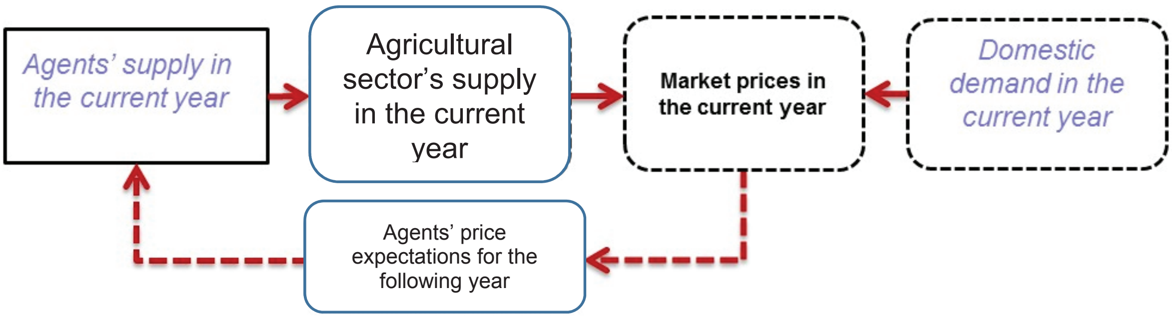

Figure 6.1: Linking agents' supply with a partial equilibrium model.

For the simulation runs, we currently use a server whose hardware configuration in 2015 is shown in Table 6.2. A simulation run for one year with 16 municipalities solved in parallel takes about 90 minutes when both the supply and the demand modules are active; without the demand module, a simulation run takes about 45 minutes. At present, we test several software and hardware options concurrently in order to reduce the simulation time.

6.3 Repast as an agent-based modelling platform

With its different flow charts, Repast serves as a tool for managing and controlling the agents. Each (farm and plot) agent in Repast is linked to corresponding objects in the SWISSland Java library, into which large sections of the models, the logic and the connection to the external systems are packed (Fig. 6.2). Repast is built on top of Java, and uses the library. The functionality provided by Repast therefore allows us to manage individual diagrams as well as the sequence of agent actions and interactions.

The logic behind the optimisation is located inside the library, which ensures that we always have a consistent view of the data. For this, only the state of the Java objects is relevant. To establish this cooperation, Java provides an interface that allows Repast to execute operations in the library in order to forge ahead with the simulation and initiate the selected simulations and optimisations. Repast can be thought of as the manager of all the agents, but without in-depth knowledge of what exactly happens in the model if an agent (farm) exits from farming or is handed over to the next generation. Repast therefore merely sends requests to the library such as: "Create new plot", "What age is farm manager of agent XY?", and the like. Based on the responses to these requests, Repast can follow different paths in the flowcharts and send further requests to the library.

The request sequence is controlled in Repast. All types of agents (farms and plots) appearing in the model are generally defined in Repast. Separate flowcharts are created for each of these types. Conditions are then added to the processes with which Repast frequently checks whether a process should be executed at a certain point in time. The conditions may be defined in different ways, e.g. they may depend on the state of each agent of a certain type, on neighbouring agents, or on other types of agents. There is only a chronological classification of the processes in SWISSLand. This means that every process is executed at a certain point in time, or in a certain sequence associated with the other processes. For the simulation in SWISSLand, a year was divided into 100 units, since most of the processes should recur every year: for example, if the flowchart starts at point 4, it will be at 4 in the first year, 104 in the second, 204 in the third, and so on.

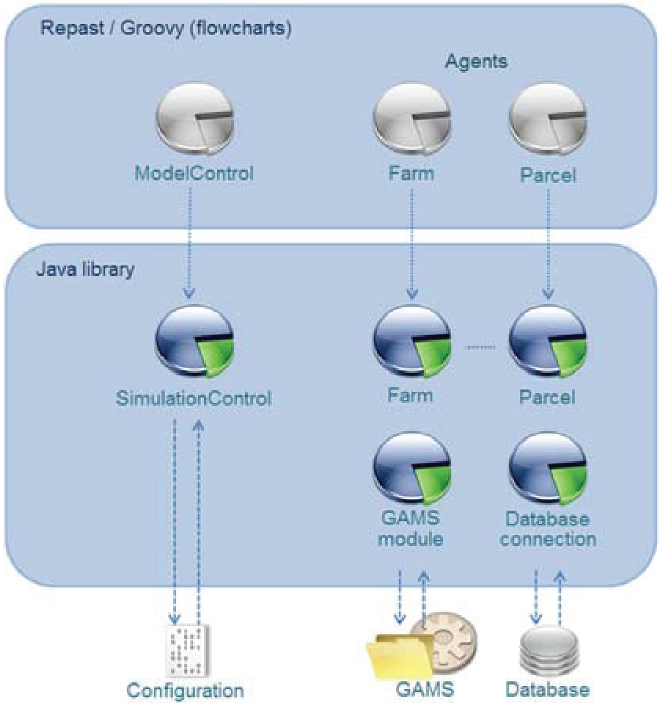

Figure 6.2: Linking Repast and Java.

There are three different types of agents in the SLSimulation model: farms, plots, and the special "ModellSteuerung" (= "model control") type.

The entire system could be implemented either in Java or in Repast. The thoughts behind the precise differentiation between Java and Repast are as follows:

a) A number of required software features (agent-based modelling, simulation management) are already implemented within Repast.
b) The workflows provided by Repast could be modified with minimal effort and without any knowledge of Java.
c) Software features which need to be robust, tested and self-contained, work best inside the Java library.

Repast uses Groovy as a programming language, in addition to the graphical user interface which makes use of flowcharts (Fig. 6.3). These flowcharts can be read and

Table 6.2: SWISSland server hardware in 2015

System	
Processor:	Intel(R) Xeon(R) CPU E5-2690 0 @ 2.90GHz 2.90 GHz (2 processors)
Installed memory (RAM):	128 GB
System type:	64-bit Operating System

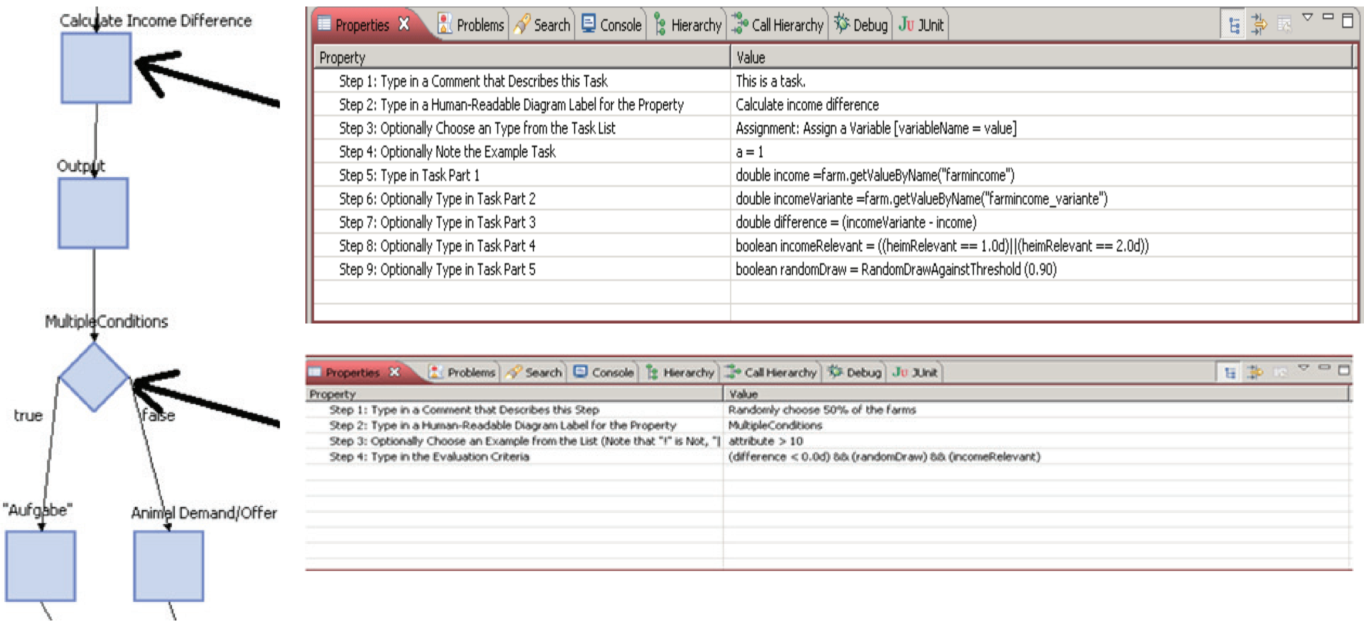

Figure 6.3: Repast flowchart (example).

interpreted easily, but are not always as efficient to implement. Moreover, they are unsuitable for complex systems and relationships. Groovy is a scripting language which is not compiled, and which thus only indicates errors at runtime 1.

As a rule of thumb, it can be said that when the logic requires more than one or two Repast tasks consisting of five lines of code each, it is probably big enough to be moved to the library as a new function provided that it can be programmed sufficiently flexibly. It might also be suitable to move it to the Java library with an appropriate parameterisation. If the same functionality is reused on several parts of the diagram, this is a good reason for encapsulating logic in Java. Instead of copying the same section of code, it can be provided in Java and called by different parameters suited to the current requirements.

7 Validation, Visualisation and Communication

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Validation of the model system represents a special challenge for agent-based models. On the one hand, sources of error can crop up in the program's syntax; on the other, however, they can also lurk in the logic of the program itself. Ultimately, the issue is whether the generated simulation result actually reflects the system and the question to be answered, or whether we are merely dealing with a random representation.

Various publications deal extensively with this subject (Balci, O. (1994); Zeigler, B.P. *et al.*(2000)). It goes without saying that a complex model like SWISSland must go through various validation steps and methods before it can usefully be used for policy evaluation. Klügl, F. (2008) describes a validation method especially for agent-based models, which was also ground breaking for our approach to SWISSland model validation. Of course, we had to adapt the process suggested by Klügl (2008) marginally in order to cover the needs of our model. The SWISSland validation process is schematically represented in Figures 7.1 and 7.2.

As early as the concept phase of the model, contact and exchange with scientific experts was sought with a view to learning from the experience of these experts and determining the methods of other research institutions in the field of agent-based modelling in the agricultural sector. This discussion with experts was therefore a first step of "conceptual validation".

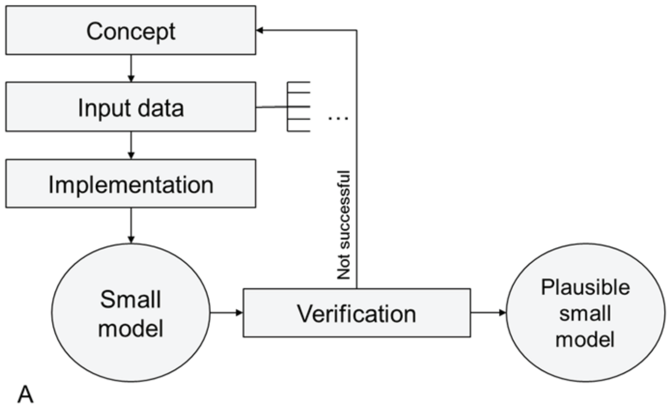
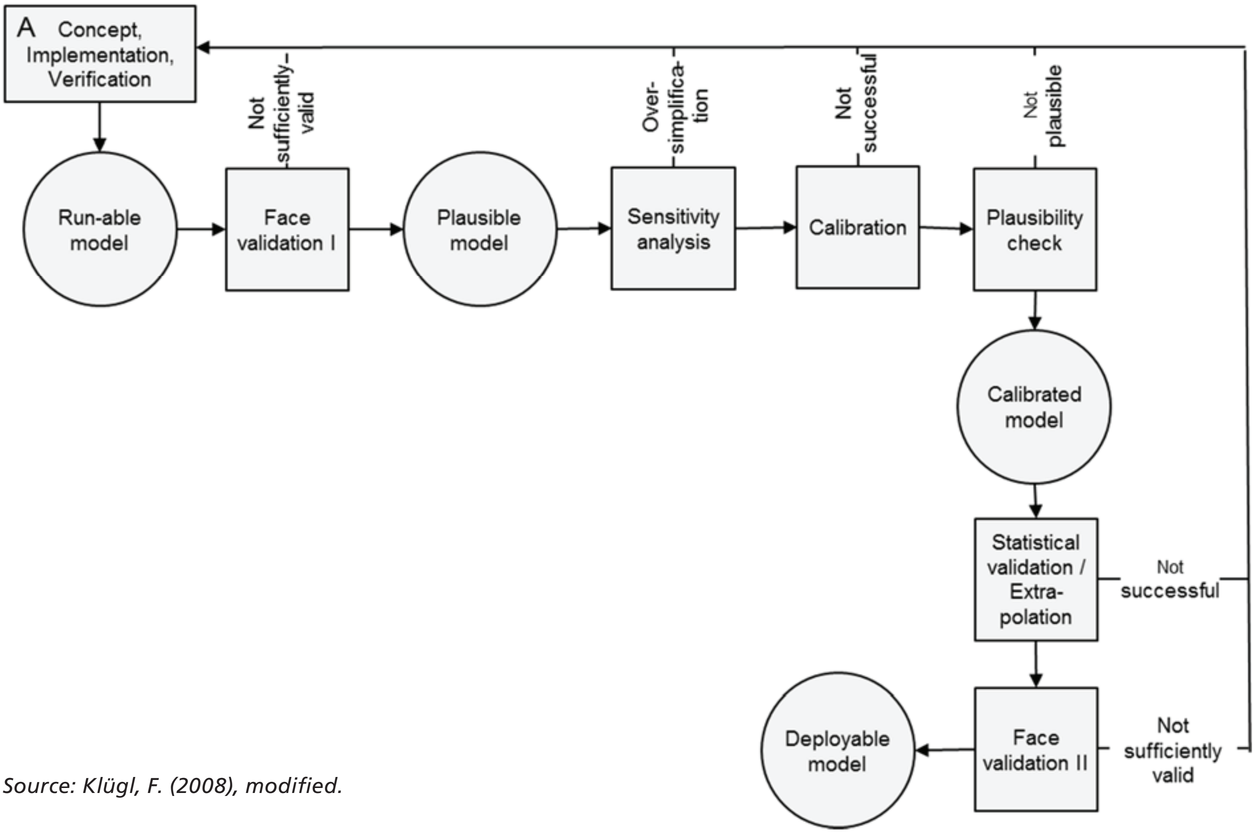


Figure 7.1: Conceptual validation framework in SWISSland.

Depending on their intended purpose and their processing stage, input data also underwent various plausibility



Source: Klügl, F. (2008), modified.

Figure 7.2: Validation process in SWISSland.

checks. They were therefore validated:
- At the time of data collection;
- At the time of data preparation before the simulation;
- At the time of implementation; and
- At the time of results preparation after the simulation.

Test loops, including verification and validation testing, had to be carried out repeatedly when the input data were implemented. The model underwent countless verification steps, beginning with the testing of the methods used to derive and prepare missing data, including the behavioural models to be used, the definition of rules and temporal processes, through to group formation with the help of statistically derived clusters for incorporating the Bayesian Networks in the model.

In order to structure this validation step in a more resource-efficient manner, we varied the size of the model. Working with so-called "small models" is very helpful for standard debugging – facilitating, among other things:
- Verification of the model code;
- Verification of data exchange at the interfaces;
- The calibration of the base year for each individual agent;
- Model validation for smaller groups of agents;
- The Validation of individual modules; or
- The validation of individual years.

Only after completion of this phase does the actual validation process for the entire model begin, since a "plausible small model" does not yet guarantee the plausibility of the entire model, including its structural and sectoral validity (Figure 7.2).

Our run-able model has therefore already completed an extensive validation process in the development phase. We can speak of a run-able model once all the modules, including the demand module, are running simultaneously, the entire projection period can be simulated, the entire agent population can be modelled, and characteristic output descriptors are identified and usable. SWISSLAND possesses a separate output tool for preparing the model output in such a way that it is actually usable for the individual validation steps. This tool makes it possible to read in the necessary output key figures from the database, and to extrapolate the results to the sector as well as output them in the desired data format and aggregation level in each case. At the same time, it is possible to use the output tool to supply data for other model applications in order to expand the system boundaries of SWISSland and increase the significance of the data through the interdisciplinary use of the SWISSland results. This also increases the possibilities of visualising and communicating the SWISSland results. The output process is outlined in Figure 7.3.

Only once these fundamental preparatory steps are concluded does the actual model validation begin – in a first step, with face validation.

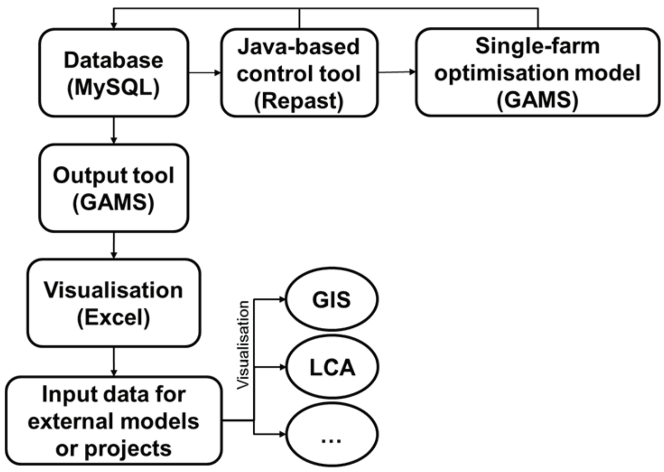
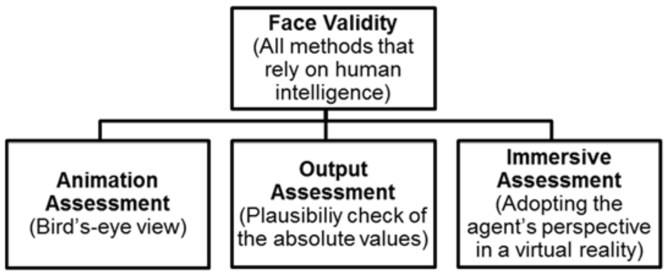


Figure 7.3: Software interfaces in the visualisation of SWISSland results.

Examples of face validation are structured walk-through, expert assessments of descriptions and animations of results. "Thus, face validity shows that processes and outcomes are reasonable and plausible within the context of a theoretical basis and the implicit knowledge of system experts or stakeholders" (Klügl, 2008). Thus, face validation consists of three methodological elements (Fig. 7.4):



Source: Klügl F. (2008), modified.

Figure 7.4: Elements of face validation.

Based on an example, the following section describes this validation step for the SWISSland model.

7.1 The benefit of a baseline scenario

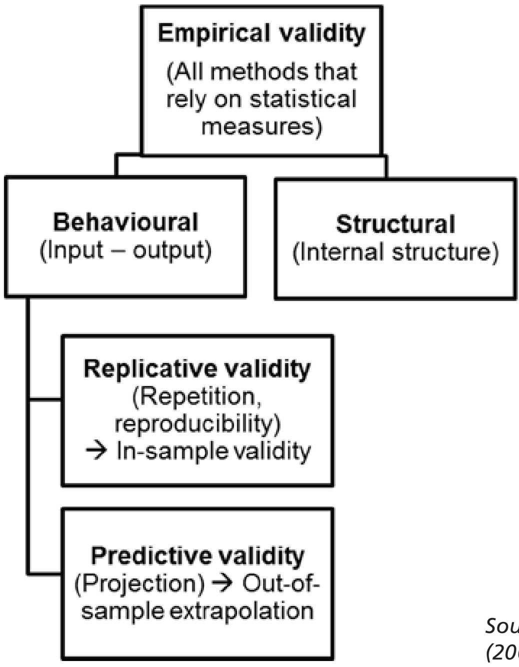
Appearing in 2015, "SWISS Agricultural Outlook" (SAO) 2014–2024 was the first publication to provide medium-term trend estimates of important key socioeconomic figures in the Swiss agricultural sector (Möhring *et al.*, 2015). The SWISSland model system was used to create the SAO. This pilot project aimed on the one hand to identify long-term relationships and driving forces of the Swiss agricultural sector, and on the other, to develop and consolidate the assumptions made about exogenous and policy-driven variables in tandem with policy decision-makers and representatives of organisations in the agriculture and food sector, as part of an expert-based discussion (see also chapter 8).

The steps in developing the baseline scenarios were the following:

1. Differentiation of the macroeconomic background.
2. Definition of the relevant national and international framework conditions.
3. Definition of the product markets and the relevant key output figures.
4. Installation and adaptation of the SWISSland model system for the implementation of points 1–3.
5. Two-way participatory exchange within the context of expert workshops for verification of the exogenous assumptions and estimation of their future trends, as well as for validation of the results.
6. Further adaptations of the model and, if necessary, calibrations of the assumptions as well as of the exogenous trend projections.

The upshot was a consensus scenario whose results simultaneously serve as a baseline for future ex-ante policy-impact assessments.

After completion of the plausibility checks, the empirical validity was tested. "Empirical validation uses statistical measures and tests to compare key figures produced by the model with numbers gathered from the reference system. The reference system is mostly the original real-world system" (Klügl, 2008). Again, the author distinguishes between various dimensions (Figure 7.5). Based on three examples the following sections describe this validation steps.



Source: Klügl F. (2008), modified.

Figure 7.5: Elements of empirical validation.

7.2 The benefit of sensitivity analysis

The aim of the sensitivity analysis is to analyse how robustly the model responds to selected key indicators when exogenous model assumptions are changed. In SWISSland, both exogenous assumptions about conditions at the macroeconomic level (e.g. population growth, GDP growth, exchange rate) and assumptions about the operationally relevant influences at agent level (e.g. technological progress) are made. Table 7.1 shows the results of the sensitivity analysis on the basis of the key figure "net entrepreneurial income". The model exhibits a high sensitivity with the parameters "exchange rate" and "increase in milk-yield", and reacts less sensitively to a slowdown in population growth or a change in GDP growth.

Table 7.1: Sensitivity analysis: changes in net entrepreneurial income (in Mio. CHF)

Scenario	Population Growth from 2014 onwards	GDP Growth from 2014 onwards	Exchange Rate from 2015 onwards (CHF per €)	Increase in Milk Yield per Cow and Year	2010	2014	2024	Direction	Sources
SAO	0.5% p.a.	1.0% p.a.	1.05	0.99%	2865	3257	3330	↗	Population growth: SFSO (2008–13); Own assumptions of Agroscope/FOAG from 2014 onwards
V0	0% p.a.	0% p.a.	1.05	0.99%	2865	3268	3373	↗	GDP growth: SECO and FOAG
Vmax	0.9% p.a.	2.0% p.a.	1.05	0.99%	2865	3273	3375	↗	Exchange rates, all (except for WK09): SNB, SECO (2015–2024)
WK09	0.5% p.a.	1.0% p.a.	0.90	0.99%	2865	3311	3072	↘	Exchange rates, WK09: SNB, own assumptions of Agroscope/FOAG (2015–2024)
WK12	0.5% p.a.	1.0% p.a.	1.20	0.99%	2865	3277	3613	↗	Increase in milk yield: SBV (=Swiss Farmers' Union), 2000–2012; Expert estimates, Agroscope's assumption
Milk_C	0.5% p.a.	1.0% p.a.	1.05	0.00%	2865	3265	3103	↘	

7.3 The benefit of ex-post scenarios

We felt it was important to show how the model reacted over time and whether the core variables matched the actual observed values. The ex-post evaluation was carried out for the period 2005–2012, with the 2003–2005 three-year average as a base year. Over this period, Swiss agricultural policy changed significantly, particularly regarding milk and meat production. To cite an example, Switzerland concluded a free-trade agreement with the EU in 2007 regarding cheese. The same year saw the country's gradual withdrawal from the milk-quota system (FOAG, various years; Mack and Pfefferli, 2004), as well as the introduction of direct payments for dairy cows. These and all further policy framework conditions decided on during this period form the exogenous bases for the agent's production decisions.

SWISSland benefits from a decisive advantage in that its main data source consists of FADN, i.e. time series, data. Not only do FADN data provide essential structural and economic farm indicators, thus supplying information on the decision-making behaviour of individual agents over time; they also allow us to draw conclusions regarding sectoral developments. It therefore made absolute sense to use this database as the foundation for an ex-post analysis.

Figure 7.6 shows the main questions that should be answered in the ex-post validation.

Additional information on methodological approach and on the results of this ex-post analysis has already been published elsewhere in various publications (Chapter 8, Möhring (2013); Mack *et al.* (2015); Zimmermann *et al.* (2015)).

In a final validation step, we use the knowledge of third-party experts. In principle, this step follows a face-validation approach as described above.

7.4 The benefit of project-based scenario analysis

Advantages in cooperating with third-party experts within the framework of interdisciplinary projects are inter alia that model expansions or model adaptations of individual modules can be professionally monitored and better supported in terms of methodology, and that the results of the agent-based model:

- Are subject to a further plausibility check through the interfaces with other models;
- Pose other validity problems owing to preparation on a new aggregation level.
- Moreover, the exogenous model assumptions can be tested by third parties and squared with model assumptions of further models.

In various project-based scenario analyses carried out with SWISSland (e.g. Möhring, 2015; Keller *et al.*, 2012) it was shown that in some cases the boundaries of significance of the SWISSland model had to be shifted. Sometimes they had to be limited, other times it was possible to expand them. In addition, new options arose for visualisation and communication through use of the interfaces with other output tools.

In summary, we might say that the validation process not only serves to ensure that the model is considered to be a valid portrayal of the system depicted, but also enables us to communicate and discuss the results with experts, stakeholders and other individuals, as well as to exchange knowledge. This leads in turn to increased acceptance of the model.

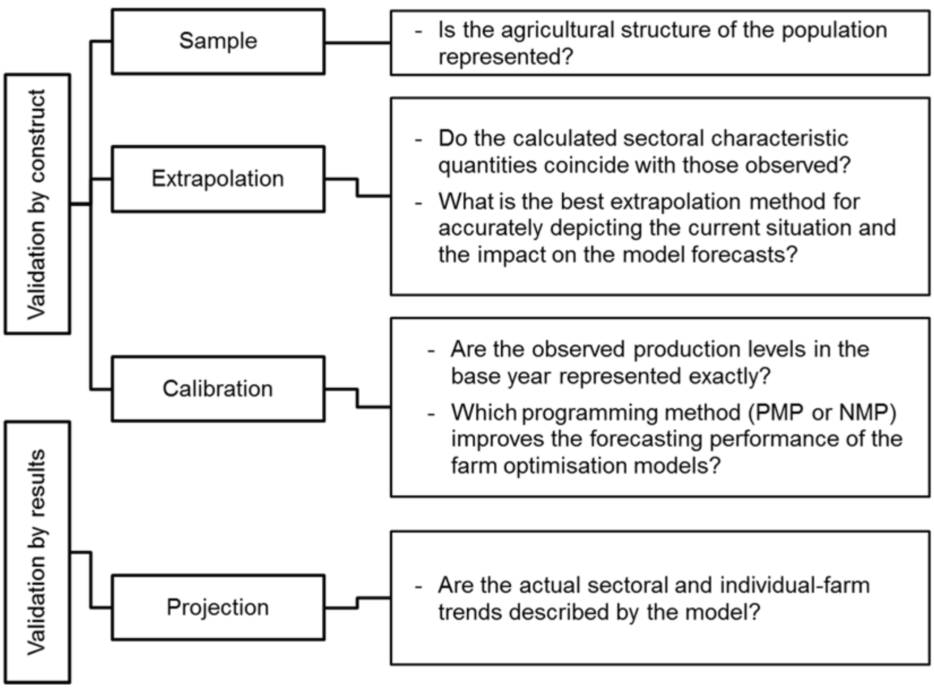


Figure 7.6: Issues regarding the implementation of ex-post scenario analysis.

8 Applications

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8.1. Using SWISSland for ex-ante policy evaluation

Based on our experience with the Swiss Agricultural Outlook pilot project, in which we published sectoral supply, demand and price trends (Möhring *et al.*, 2015), we recommend a four-step ex-ante policy evaluation:

Determination of all model-exogenous macroeconomic parameters

The main model-exogenous macroeconomic parameters driving domestic demand for agricultural products are (1) Swiss population trends, (2) Swiss income trends, and (3) the exchange rate of the Swiss franc. The exchange rate of the Swiss franc to the euro substantially influences imports and exports of agricultural products, as well as the prices of agricultural inputs. When compiling the Swiss Agricultural Outlook (SAO), we used forecasts provided by the Swiss Federal Statistical Office (SFSO), the Swiss State Secretariat for Economic Affairs (SECO), the Federal Office for Agriculture (FOAG) and the Swiss National Bank (SNB) (Table 8.1). Gross domestic product was used as a proxy for income trends in the SAO.

Table 8.1: Forecasts for the main macroeconomic parameters used in the Swiss Agricultural Outlook

Parameters	Forecasts	Trends	Exogenous Input for SWISSland Module
Domestic population	Swiss Federal Statistical Office (SFSO) (2008–13); Assumptions by Agroscope/ FOAG from 2014 to 2014	Average increase of 0.5% p.a. in the domestic population	Demand module
Gross domestic product	SECO (2008–2013); Assumptions by Agroscope/ FOAG from 2014	Average increase of 1.0% p.a.	Demand module
Exchange rate	SNB (2008–2014); Assumptions by Agroscope / FOAG from 2015	CHF 1.05 per €	Demand and supply modules

Determination of the model-exogenous national and international agricultural-policy parameters

International product-price trends of the European and world markets substantially influence Swiss product-price trends. For the Swiss Agricultural Outlook, we used exchange-rate-adjusted world price trends provided by the EU Commission (Table 8.2). These forecasts are also used in the CAPRI model system, and guarantee consistency with the latter. Model-exogenous national policy parameters driving the supply of agricultural products are direct payments, input-price trends, threshold prices for fodder-concentrate markets, and the budget for milk-market support. These parameters were forecasted in collaboration with Swiss Ministry of Agriculture experts.

Table 8.2: National and international forecasts for agricultural-policy parameters used for the Swiss Agricultural Outlook in 2015

Parameters	Forecasts	Trends
EU and world-market prices	DG AGRI and FAPRI[1]	Exchange-rate-adjusted trends
Cost indices for inputs and investments	SBV (= Swiss Farmers' Union) (2008–2014); Assumptions by Agroscope / FOAG from 2015	Trend extrapolation and experts' assumptions
Direct payments	FOAG	Payments as per Swiss Agricultural Policy 2014–17
Threshold prices for concentrates	FOAG	As per Swiss import legislation
Market support for milk	FOAG	Budget approved by the Swiss Parliament

[1] *World-market price trends for products, which are not available from the European commission, were taken from the FAPRI model by Iowa State University and the University of Missouri, and consist mainly of processed soya and sunflower products.*

Determination of model-exogenous yield trends and labour-related productivity growth

The yields of the production activities are estimated for each agent on an individual-farm basis from the FADN data of the base year, which represent an average over three years. This means that the heterogeneity of crop and animal yields among agents owing to different locations and management methods are taken into account, whilst weather fluctuations and extreme weather events are ignored. Since crop and dairy-production yields have increased substantially over the past 50 years, we have assumed that the yield trends observed since 2000 will persist over the next 15 years. For the Swiss Agricultural Outlook, we used weighted arithmetic means of the percentage annual yield increase from the years 2000 to 2012.

Determination of the output parameters

We determine the output parameters and their degree of aggregation (farm-type averages, extrapolations to regional and sectoral scale) for ex-ante evaluations with the clients of the evaluations. Table 8.3 shows the available supply and demand output parameters from the SWISSland model. A selection of these parameters is normally published in reports for the Federal Administration or in articles in journals.

Table 8.3: Potential output parameters of the supply and demand modules

Output parameter	Description	Scale
Supply Module		
Land use (ha)	For 27 crop-production activities	Farm types/Regional/Sectoral
Livestock (LU)	For 15 animal-production activities	Farm types/Regional/Sectoral
Number of farms		Farm types/Regional/Sectoral
Income (CHF)	Agricultural income/Household income/Sectoral income	Farm types/Sectoral
Production costs (CHF)	As per the FADN System/ As per the EAA	Farm types/Sectoral
Gross production (CHF)	As per the FADN System/ As per the EAA	Farm types/Sectoral
Direct payments (CHF)		Farm types/Regional/Sectoral
Agricultural production (t)	Products as per the CAPRI system	Sectoral
Extensive land use (ha)		Farm types/Regional/Sectoral
Mineral-fertiliser input (t)		Farm types/Regional/Sectoral
Concentrate input (t)		Farm types/Regional/Sectoral
N- Surplus		Farm types/Regional/Sectoral
Demand Module		
Consumption of agricultural products (t)	Products as per the CAPRI system	Sectoral
Import of agricultural products (t)	Products as per the CAPRI system	Sectoral
Export of agricultural products (t)	Products as per the CAPRI system	Sectoral
Prices for agricultural products (CHF)		Sectoral

9 Conclusions

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No model is as good as reality. Even so, a model allows us to look into the future, play with different scenarios, and envisage a number of alternatives.

SWISSland goes a long way towards depicting agricultural reality as closely as possible. It is no easy matter to find algorithms that approximate behavioural patterns shown by a significant percentage of Swiss farmers.

We can always do better. The problem lies in the difficulty of defining these potential improvements. Since it sometimes takes more than a day to run a scenario, the reduction of complexities, resulting in faster optimisation processes, may be considered a substantial improvement. On the other hand, there are many important building blocks of farm production that are still completely ignored by SWISSland, including pesticide application, different feeding regimes, or competing livestock-housing systems. Their inclusion in the model, whilst technically possible, would result in even longer optimisation times – and there is no demand for a simulation model that actually takes up the entire future for which predictions are supposedly made!

A sense of curiosity is appropriate here. Will we see technical developments that reconcile the contradictions described, possibly through the development of hardware that is much more efficient than current servers? Or will we identify forecasting models which do not need to refer to individual decision-making units? Whatever the future holds, this continues to be a fascinating and rewarding research topic!

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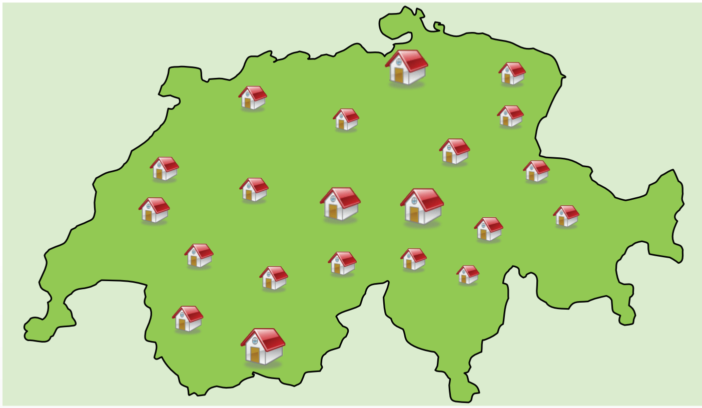

Agent-Based Modeling on a National Scale – Experiences from SWISSland

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