Table of Contents

Go Back

21st International System Dynamics Conference
New York, July 20-24, 2003

Policy and outcome contrasts in the evaluation of the effects of structural change in Swiss mountain agriculture using Linear Programming and System Dynamics

Birgit Kopainsky, Christian Flury, Peter Rieder

Agricultural Economics, ETH Zentrum, CH-8092 Zurich, Switzerland

phone: +41-1-632 53 28, fax: +41-1-632 10 86

E-mail: birgit.kopainsky@iaw.agrl.ethz.ch, christian.flury@iaw.agrl.ethz.ch,

peter.rieder@iaw.agrl.ethz.ch

Zurich, May 16, 2003

1 Introduction

Structural change in Swiss agriculture has been continuing over the last decade. This has not only led to a decline in agricultural employment and income generation, but also to land use changes with far-reaching consequences for the provision of landscape and ecology related public goods. Most affected by this development are peripheral regions in the Swiss Alps. They have at the same time experienced considerable support from regional policy measures in the past. However, both agricultural and regional policy are undergoing fundamental changes as a reaction to the effects of world trade liberalization, international integration and increasing national budget limitations. The policy measures therefore become increasingly decentralized and restricted to innovative projects based on local and regional initiatives. The task of local and regional decision makers has consequently shifted from implementing national strategies to launching and moderating such initiatives. A region's survival and quality of life no longer depend on the amount of money paid by the Federation, but on the initiation and the appropriateness of autonomous development strategies. Hence, decision support tools are required both for evaluating the effectiveness and efficiency of new national or sectoral policy concepts and for estimating the economic, social and ecological impacts and trade-offs of specific local or regional development projects. Simulation and optimization models have proved useful in providing decision support for the development of effective and efficient policy measures.

This paper explores the suitability of two different model types for addressing the above mentioned issues. We distinguish between a linear programming model and a system dynamics model with which we evaluate different development and policy scenarios for agriculture in the Swiss Alps. The models provide insights into the processes underlying agricultural development and their main influencing factors. We compare policy outcome and policy contrasts by applying the two models to the same question, i.e. to the effects of structural change in agriculture on employment, income, land use and the provision of public goods. We analyze which and whose questions can be asked to the models and what answers and policy implications can be queried from the models, especially if the questions are the same.

The questions arise from the characteristics and problems of Swiss mountain agriculture and are illustrated in section 2. In section 3 and 4 we describe and compare the models that were developed for the analysis of these problems. The results generated by the models are displayed in section 5. Based on the comparison of model characteristics and on optimization and simulation results, respectively, we draw conclusions concerning the suitability of the two models for different decision makers and for applied research in section 6.

2 Importance of agriculture in Swiss mountain areas

In the course of economic development, agriculture's productive contribution decreases and the importance of the provision of public goods and of (positive) external effects increases (Flury *et al.* 2002). In Switzerland agriculture contributed only one percent to the gross value in 2000 using as much as 3.5 percent of the full-time workforce (SBV 2001).

Despite its declining economic role, agriculture still retains its spatial responsibility: more than one third of the Swiss area is under agricultural cultivation (SBV 2001). Furthermore, land use offers numerous examples of spatial environmental externalities (Bouman *et al*. 1999). Soil erosion, loss of habitats, increased vulnerability of soils and loss of natural amenities are manifestations of the negative effects of land exploitation. On the other hand, appropriate land use activities prevent the emergence of these negative externalities. These types of spatial externalities are particularly pronounced in mountain areas where, for instance, fallow land may generate negative external effects (Flury *et al.* 2000). In these regions agricultural land use is also very important for landscape conservation as it is a significant asset to the tourist industry. Additionally, agriculture has long been the central economic sector in mountain regions, thus fostering and maintaining settlement, economic and social life in remote areas (Errington 2000).

There is consequently considerable interest in the further development of agriculture, especially in mountain areas. Based on the above mentioned private and public goods provided by agriculture we were interested in the following three aspects: development of land use, agriculture's contribution to employment and to total value added.

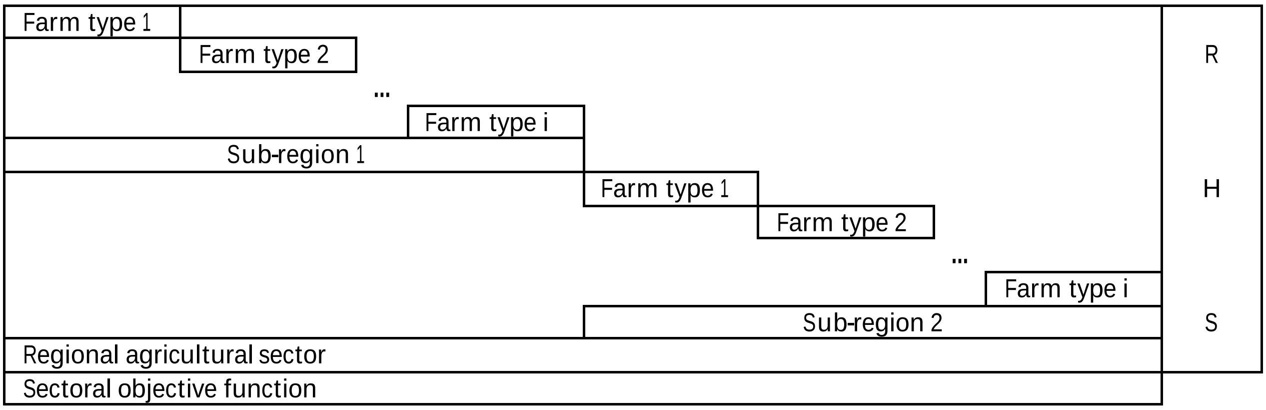
We examined these aspects in a case study region in the Swiss Alps: The Muenstertal is situated in the south eastern part of Switzerland. It consists of six villages situated between 1200 and 1900 meters above sea level and is characterized by negative population development and a high share of agricultural employment (23 percent on average). In the year 2000 61 farms were counted. Together, they cultivated a total of 1016 hectares. The Muenstertal is delimited by the Italian border to the south, high mountains to the east and west and the Ofenpass to the north, thus forming a well-marked regional system with easily definable exchange relations to adjacent regions and the rest of the world.

3 Description and comparison of the models

3.1 Linear programming model

The linear programming model is a comparative-static sectoral optimization model (see Figure 1) the objective of which is to maximize the sectoral revenue of agriculture in the region under consideration. This is achieved by the optimal allocation of scarce production factors to farm types in different sub-regions or communities, respectively, giving due consideration to the restrictions of each level of aggregation (farm, community or region). This means that the overall sectoral structure is optimized simultaneously in a way which results in a maximum payment of production factors according to the criterion of comparative cost advantage. A sector model helps to explain producers' reactions to external changes, such as prices or policy measures. Important information on the producers' expected reactions can be obtained by solving the model under different assumptions on policy parameters or policy measures (Hazell and Norton 1986).

Figure 1: Structure of the linear programming model (RHS=Right Hand Side)[1]



The main focus of the model is the detailed representation of land use. This allows for an accurate ex-ante evaluation of different direct payment schemes. In addition, the model includes indicators for the evaluation of different development and policy scenarios. These indicators are some of the structural components of the linear programming model: activities, restrictions and objective function (Figure 1). Sub-regions were defined conforming to the borders of the six communities. Within each community, five farm types compete for the available land. Grassland is used for different types of cattle (dairy or nursing cows, beef or calf production, cattle rearing) and sheep. Various cropping activities are possible (maize, barley, potatoes, wheat). Full-time and part-time farms are included and land can be used at two different levels of intensity.

In the Right-hand side of the model spatial data are integrated as restrictions. The model includes the following spatial data from different geographic information systems and from public statistical databases on a per hectare grid:

- Agricultural land in each community, subdivided into six altitude levels (<600 m, 600-1800 m in steps of 300 m, >1800 m above sea level) and four slope categories (<18%, 19-35%, 36-50%, >50%).
- Physical yields for each hectare and for different land use activities (grassland, hay, silage, pasture), based on digital information of the cultivation suitability map and on expert judgment.
- Input requirements (labor, mechanization, fertilizer) as a function of land use activity (grassland, hay, silage, pasture) and of the topographic situation (altitude, slope).

Restrictions were mainly formulated on two levels of aggregation: 1) On the farm level all production-related restrictions are expressed (crop rotation, animal feeding, fertilization, cattle and sheep rearing, labor etc.). Additionally, legal constraints for participation in direct payments were included. 2) On the community level, restrictions concerning factor markets were defined (available land on respective altitude level and slope category, balance of leased land and of labor).

In the optimization process for a given scenario, sectoral revenue (total of all farm revenues) is maximized simultaneously over all farm types and communities while at the

---

[1] For more details on the structure and components of the linear programming model see Appendix 1.

same time adhering to the restrictions on the farm and community level. The total revenue on the farm level is calculated as follows:

Revenue from agricultural production and direct payments
+ additional non-agricultural income
- direct costs (mineral fertiliser, feeding concentrates, seed, plant protection)
- machine and building costs
- costs for hired labor
± revenue and costs of leased land
= Total revenue on farm level

The model is programmed in AMPL (Fourer *et al.* 1993), an index-based programming language. With the help of this software, the basic structure of the database (indices and sets) is defined and the linear programming matrix is generated. The database is handled independently from the model with an input generator in the relational database software Microsoft Access 97 (Keusch 2000). The optimization is accomplished by applying the CPLEX barrier algorithm (CPLEX User Guide 8.5.3) on a high performance parallel-scalar computer server. Further details on the structure of the model and technical information can be found in Flury (2002).

The original model was developed for the overall Swiss Alpine region. It was used as a communication and synthesis tool within the scope of the multidisciplinary research program "PRIMALP — Sustainable primary production in the Alpine region" at ETH Zurich (see www.primalp.ethz.ch).

3.2 System dynamics model

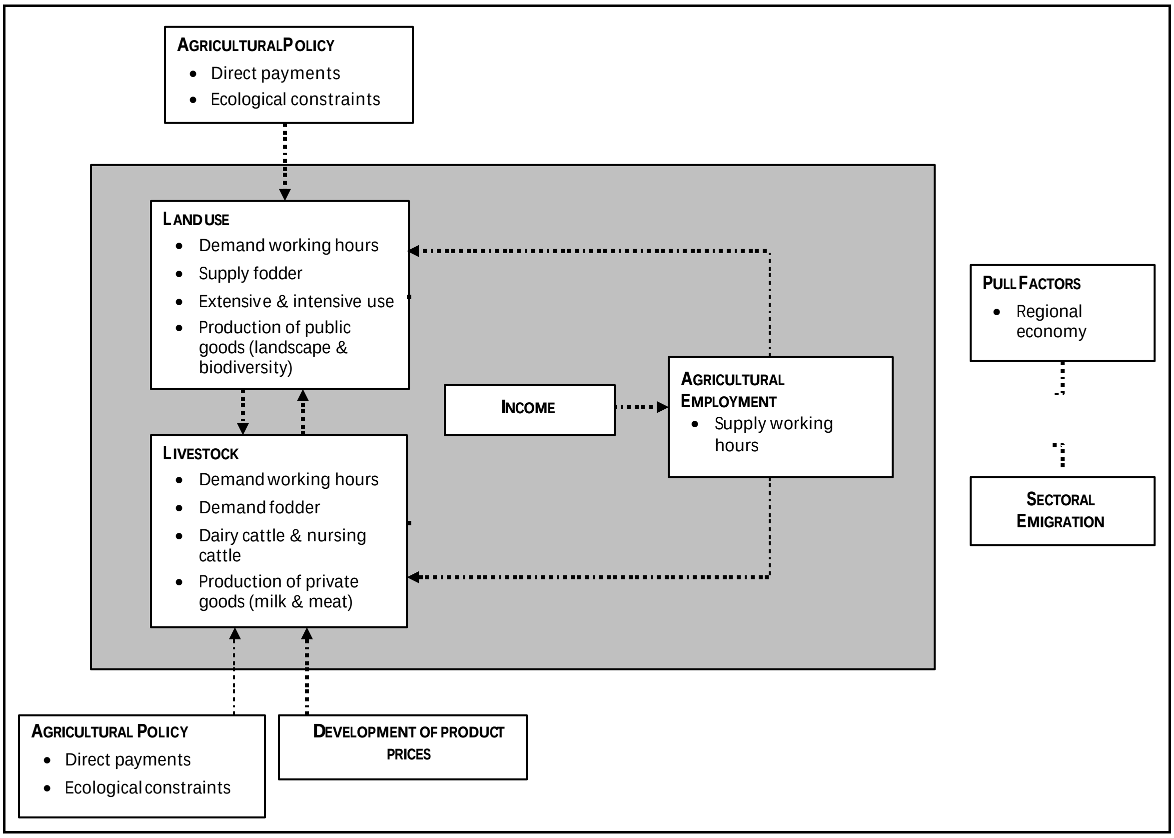
The system dynamics model shows the agricultural part of a greater system dynamics model on regional rural development. The purpose of the overall model is to test the effects of economic development as well as of agricultural and regional policy scenarios on the different functions of rural areas.[2]

The agricultural part represents livestock farming, land use and their combined effects on and interrelations with employment and income generation. The model is conceived for a time horizon of twenty years. This allows for the measurement of processes with a considerable adaptation time like sectoral emigration of workforce and changeover in livestock farming (delays due to age of workforce and of stables, respectively). In Figure 2, the subsystem diagram of the model is displayed, showing the network of development-relevant issues faced by regional agriculture. The provision of public goods, of external effects and agriculture's contribution to settlement, economic and social life (see section 2) can be derived from the variables within the subsystems of land use, livestock and agricultural workforce.

---

[2] See Kopainsky *et al.* 2003 for more information on the functions of rural areas.

Figure 2: Subsystem diagram of the system dynamics model[3]



The model distinguishes between two categories of livestock (dairy and nursing cows) and three categories of land use (extensive pasture, extensive grassland and intensive grassland) some of which can fall fallow. The core part of the model involves a stock of agricultural workforce which is drained by sectoral emigration. The model consists of four components described below and was developed using the software “Vensim”.

- *Livestock farming line*: The two possible ways of livestock farming are shown: dairy cows and nursing cows. The total number of cattle is delimited by ecological constraints, labor and fodder availability. Due to changes in national and international agricultural development, milk production becomes less and less competitive, especially in mountain areas (Flury and Rieder 2003). Thus, the process only goes from dairy cows to nursing cows and not backwards. The adaptation time of this process is determined by the age structure of the stables in the region.
- *Land use line*: Land use changes are a direct consequence of changes in livestock farming (intensive to extensive grassland) and of the relation between total cultivated area and total workforce (grassland to pasture with work becoming increasingly scarce). Fallow land occurs when the maximum share of pasture is reached and work availability continues to decrease.

---

[3] For more details on the structure of the system dynamics model and its components see Appendix 2. The Vensim model in stock and flow format is available from the corresponding author.

- *Agricultural income*: In this part of the model total agricultural income is calculated. Important components of agricultural income are direct payments that remunerate the provision of public goods.
- *Agricultural employment*: The stock of agricultural workforce is drained by sectoral emigration. Emigration occurs at an adverse difference between the income generated by livestock farming and land use and the potential non-agricultural income. The delay in emigration depends on the age of the agricultural workforce and on the economic performance of the overall regional economy. Another possible cause for emigration is too big a discrepancy between demand and supply of working hours, i.e. when the agricultural workforce is not fully engaged with the available area and livestock in the region. Again this process only works one-way, as agricultural employment is highly unlikely to increase given the high transaction costs of leaving agriculture and given theory and evidence of the overall economic structural change and transformation.

3.3 Comparison of the models

In this section we compare the two models from a methodical point of view and evaluate the consequences of the choice of a model type on the thematic questions raised in section 2: development of 1) land use, 2) agriculture's contribution to employment and 3) agriculture's contribution to total value added. As a basis for this Table 1 reviews model characteristics of both the linear programming and the system dynamics model.

Table 1: Comparison of the two models

Criterion for comparison	**Linear programming model**	**System dynamics model**
Model purpose	Synthesis of interdisciplinary research on mountain agriculture, evaluation of agricultural policy measures Focus on agricultural land use and sectoral development	Understanding of local rural development processes, evaluation of regional policy measures Focus on stability and adaptation processes
1. Model type	Comparative-static sectoral optimization model	Dynamic regional simulation model
2. Model structure	Different farm types, communities and overall region	One virtual farm for the entire region under consideration
3. Time horizon	10 to 20 years	20 years
4. Underlying theory and relevant discipline	Microeconomic theory Operations Research	Microeconomic theory Systems Theory & System Dynamics
5. Determinants of actor's decision making	Free decisions among possible input-output-combinations (production functions) within restrictions Decisions take into account price and cost prospects in the future	Decision rules Decisions are process-dependent, i.e. decision at time t_1 depends on the situation at time t_0
6. Level of detail	High due to model purpose Spatial disaggregation: spatial distribution of agricultural production captured	Medium (higher level of aggregation) due to model purpose Spatial aggregation: capturing of spatial distribution not possible due to model structure (single virtual farm)

Criterion for comparison	Linear programming model	System dynamics model
7. Complexity and scope of the model	Only quantitative variables High number of variables, more thematic detail but less complexity due to static approach Interdisciplinary within agriculture	Quantitative and qualitative variables Fewer variables but complexity due to numerous feedback loops Interdisciplinary in a broader sense: agriculture as part of overall regional system
8. Predictions	Prediction of optimal (from a sectoral point of view) agricultural structures that will develop after elapse of time horizon of the model (after 10 to 20 years) Measurement of scarcity of production factors by means of shadow prices Critical factors for different policy measures and production alternatives	Prediction of structural adaptations during time horizon of the model (during 20 years) Identification of irreversible processes Critical factors for system stability
9. Prediction precision	Low to middle	Rather low, focus on system behavior and not on single variables
10. Acceptance of the model and credibility of the results	Positive in relation to acceptance and credibility: high level of detail and high level of precision within assumptions about economic factors Negative in relation to acceptance and credibility: economic factors are the only influences on behavior, “expert model”	Positive in relation to acceptance and credibility: inclusion of qualitative variables, group model building and communication tool, “common model” Negative in relation to acceptance and credibility: low disciplinary precision due to holistic view
11. Transferability to other regions	Little time intensive	More time intensive, as qualitative variables have to be estimated separately for every region
12. Work input for model development	Basically higher than system dynamics model	Basically lower than linear programming model Dependent on share of qualitative variables.

Criteria 1 to 3 recapitulate model descriptions in the previous sections. Both models are economic models (criteria 4 and 5). In the linear programming model, factors are allocated according to neoclassical theory whereas in the system dynamics model, Johnson’s theory on quasi-fix factors (Johnson and Quance 1972) is taken into account. There are also different implications of the economic feature of income-maximization. In the system dynamics model, decision rules are formulated on this assumption. This implies sectoral emigration of agricultural workforce if the benchmark income is not achieved with agricultural production or if there is an over-supply of working hours within agriculture. The system dynamics model itself is a simulation model without optimization features. The linear programming model, on the other hand, truly maximizes the sectoral revenue.

The level of detail covered by the models and the accuracy of the optimization or the simulation predictions are one of the main influencing factors on model acceptance and credibility (criteria 6 to 10). However, the more participatory and holistic procedure in the system dynamic approach is probably of equal importance. Acceptance and credibility thus depend on the target group of the model and their claims to simulation results.

Criteria 11 and 12 refer to implications of model characteristics on model development and model application.

In general, Table 1 implies that the strength of the linear programming model is higher prediction precision. The linear programming model, however, cannot capture adaptation processes and over-estimates factor mobility, especially in the short term. It allows for the optimization of structural reactions to a change in general conditions and for the estimation of the consequences on income-generating production processes. The predictions are not for a specific point in time. They much rather display the kind of structures that have to be expected in the future given the simulated policy scenario and unrestricted factor mobility. If the adaptation process is of crucial importance in Operations Research, recursive-dynamic optimization has to be used. Such approaches and models were first developed by Day (1963) and De Haen (1971). Recursive programming constrains the adaptation process by including additional restrictions. For the optimization of structures at time t_1, elements from the structure at time t_0 are integrated as flexibility coefficients. The reason for this coupling is that actors' decisions at a given point in time depend on their decisions in the past (De Haen 1971).

Covering adaptation processes, delays and irreversibilities is one of the main advantages of the system dynamics model. System behavior, though, risks being rather sensitive to the values of these system elements as general assumptions on factor flexibility have to be made and decision rules have to be formulated.

4 Model validation

Once a linear programming model has been constructed, there are two broad ways in which it may be in error: 1) the matrix may be inconsistent with the problem definition, or 2) the problem definition may be incorrect or inappropriate in some way (Pannell 1997).

The linear programming model in this paper is considered as valid when it reproduces the real agricultural structures in the year 2000 in a sufficiently accurate way. Table 2 compares model results for the year 2000 (calibration) to the real situation in this year. The data used for the validation are based on information on the situation of the year 2000, obtained from different statistical databases on Swiss agriculture and from expert knowledge about the case study region.

Table 2: Validation results of the linear programming model

Variable	**Real**	**Calibration**
Agricultural workforce (persons)	53.2	54.13
Total area (hectares)	1017	1017
Extensive land (hectares)	227	199
Units dairy cattle	389	364
Units nursing cattle	841	626
Agricultural income per person (CHF)		68363.2

The comparison of the real structures and the calibration results shows that the model provides a reasonable reflection of the structural reality. All the agricultural land is cultivated. This is in keeping with the actual situation where no fallow land exists. The low number of nursing cattle can be explained by the observation that nitrogen and phosphorus nutrient balances are more binding in the model than in reality. Information on the actual agricultural income is not available on a regional basis and can only be estimated. A value for this variable is therefore not provided for the real situation.

The validation process of the system dynamics model included testing model structure as well as model behavior (Barlas 1996). Structure validation is concerned with warranting that the model's internal structure is a sufficiently accurate description of the real system, with respect to the issue of interest. Behavior validation means that the output behavior of the model reproduces closely enough the dynamic behavior of the real system under study (Barlas *et al.* 2000). For this purpose the accurate replication of the patterns for the period between 1996 and 2000 was tested (same data source as for the validation of the linear programming model). This period is rather short. There are, however, problems with data availability for the time before 1996. Additionally, Swiss agricultural policy has experienced profound changes since 1992 with far-reaching consequences on agricultural activities and actors' decision making. It is therefore difficult to compare the situation before the agricultural policy reform with the current situation without completely altering the processes covered in the model.

Tests on model structure showed high sensitivities to the values of the adaptation times. Exogenous variables proved little sensitive. Assumptions on endogenous relations like change in type of livestock and especially change in type of land use, on the contrary, had considerable impact on system behavior. This is well in line with the system dynamics notion of causally closed systems where the internal structure is much stronger to explain behavior than external influences (Richardson 1991).

Results from behavior validation are shown in Table 3. Although the absolute values of the variables differ between the simulation results for the period between 1996 and 2000 and the observed development, all the processes except nursing cattle go in the same direction and show identical behavior. The extreme difference for nursing cattle can be explained by the fact that total cattle intensity in 1996 is much higher than ecological constraints from agricultural policy would allow for and that the model only permits a correction via nursing cattle. The reaction cannot be balanced within the short simulation time of four years.

Table 3: Validation results of the system dynamics model

Variable	**1996-2000 (model)**	**1996-2000 (reality)**
Agricultural workforce	-28%	-33%
Dairy cattle	-20%	-60%
Nursing cattle	-90%	+290%
Extensive pastures	(+15 hectares)	(+11 hectares)
Fallow land	0	0

5 Model results

In this section we present optimization results from the linear programming model and dynamic patterns which the system dynamics model generated. We distinguish between the evaluation of effects of different policy assumptions for direct payments as a sectoral policy measure and the evaluation of an endogenous development strategy based on regional marketing and agricultural self-help. We analyze model results with the aim of identifying further differences in the two modeling approaches and in policy implications. Therefore, we do not comment on the results in every detail.

5.1 Model parameters and scenarios

We simulated and compared four scenarios:

1. *Local processing*: In the face of decreasing product prices the strategy of local processing and marketing has gained in relevance. This holds especially for mountain areas where consumers not only value product quality, but also the natural and socio-cultural assets that the region's name implies. The *local processing* scenario investigates the effects of a local development initiative where higher product prices can be realised through local processing and marketing of milk and meat.
2. *New direct payments*: All farmers in the mountain areas receive base payments of CHF 1'200.- per hectare. A main motivation for these payments is to ensure farmers' incomes in view of decreasing commodity prices. With the re-examination of Swiss agricultural policy a new type of direct payments is discussed, especially for mountain areas. Direct payments coupled to agricultural workforce instead of agricultural land aim at stabilising agricultural employment and thus at fostering agriculture's contribution to settlement, economic and social life. In the *new direct payments* scenario we study the effects of a change in the direct payments scheme.
3. *Combination*: For this scenario we combine the effects of the *local processing* and the *new direct payments* scenario.
4. The results of the previous scenarios are always compared to *base run* where current development trends remain unaltered in the future.

The data used for the simulations are the same as those used for model validation (section 4). The essential exogenous parameters used in the two models are given in Table 4. The assumptions for the future values of the parameters are based on estimations of the Swiss Federal Agency for Agriculture.

Table 4: Assumptions and parameters for the different scenarios

Scenario	Assumptions and parameters
Base run	Cost development (index for costs land use and costs livestock): – 1 in 2000, 1.05 in 2010, 1.1 in 2020 Price development (index for milk price and meat price): – 1 in 2000, 0.9 in 2010, 0.8 in 2020 Development of potential non-agricultural income (index): – 1 in 2000, 1.05 in 2010, 1.1 in 2020 Direct payments: constant
Local processing	Differences to base run: – Price index milk: index base run*1.065 – Price index meat: index base run*1.05
New direct payments	Differences to base run: – Decrease of base payments area from CHF 1'200.-/ha to CHF 600.-/ha between 2008 and 2012 – Introduction of direct payments workforce starting with CHF 3'000.-/person to CHF 12'000.-/person between 2008 and 2012
Combination	Combination of assumptions for *local processing* and *new direct payment*

5.2 Simulation and optimization results and thematic comparison

In Figure 3 the results from the linear programming model for the four scenarios are displayed. The results are given as percentages of the calibrated situation in the year 2000 (see validation). Figure 4 shows the dynamic patterns generated by the system dynamics model. Again, the results are percentages of the real situation in the year 2000 (year 0 of the simulation). As the simulations in the system dynamics model produced virtually identical outcomes for all four scenarios only *base run* results are displayed. The only variable that differed between the scenarios, agricultural income per person, is depicted in Figure 5.

Figure 3: Optimization results from the linear programming model for the four scenarios

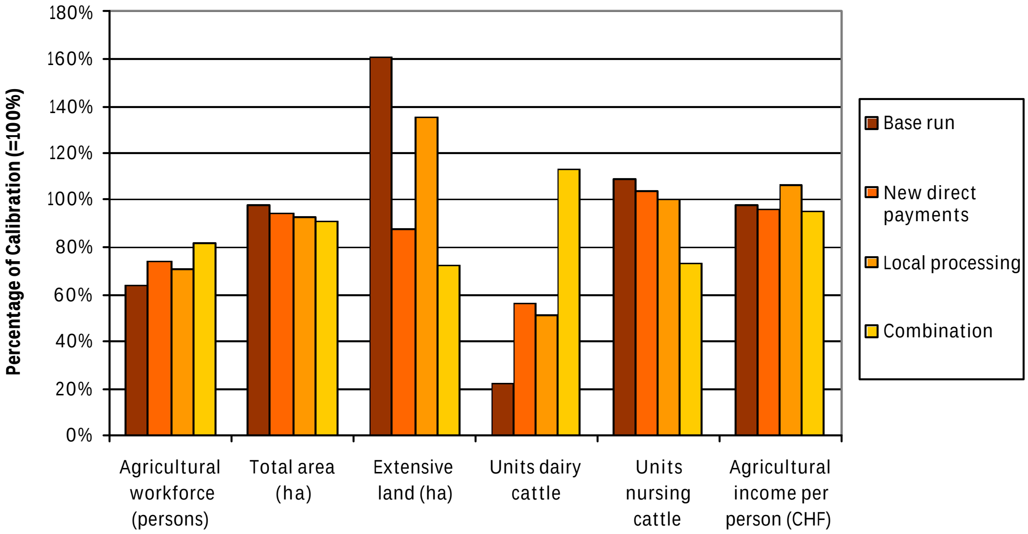
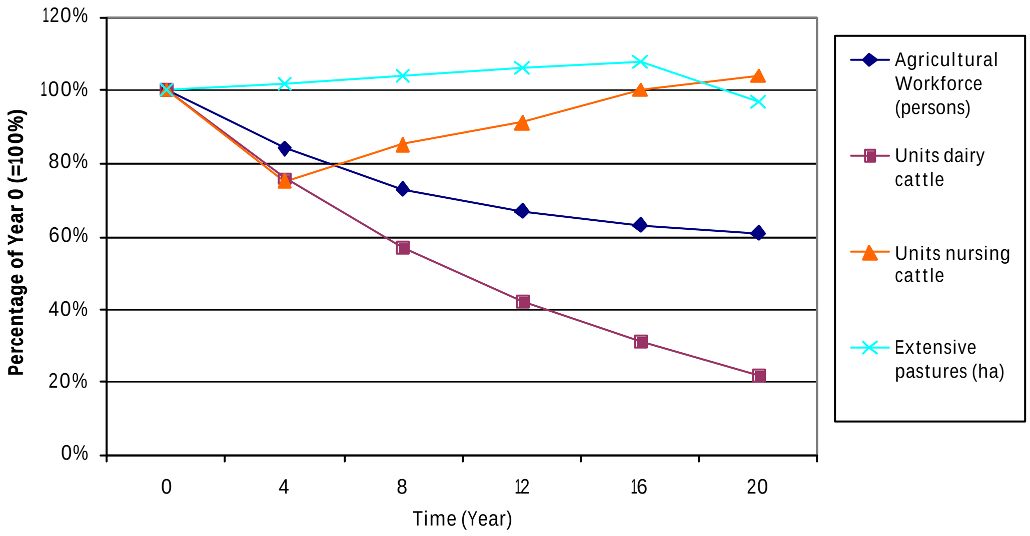


Figure 4: Simulation results (base run) from the system dynamics model



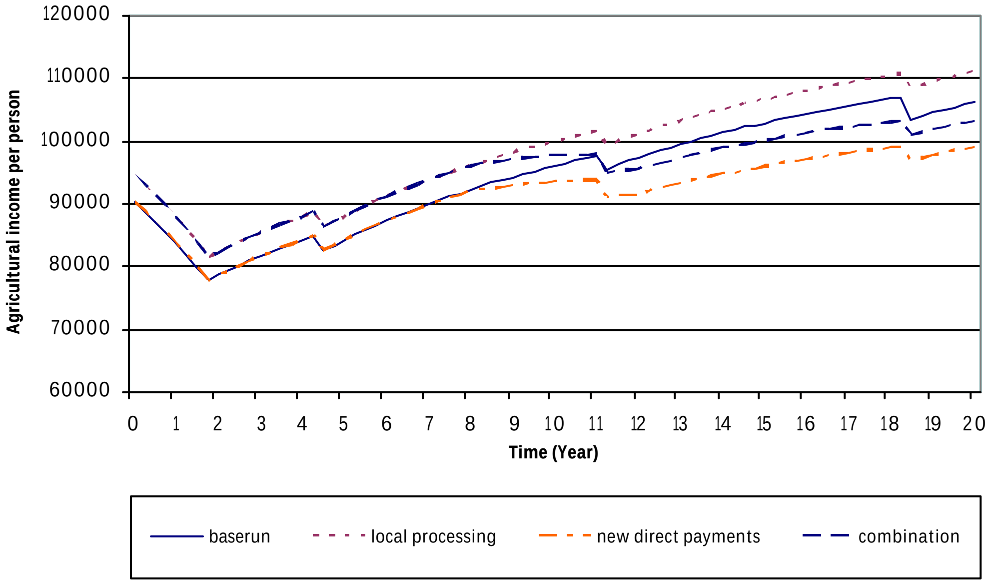
A comparison between the results of the linear programming model and the situation for year 20 in the system dynamics model shows a high degree of congruence. Agricultural workforce is reduced to a bit more than 60 percent and livestock experiences a marked shift from dairy to nursing cattle. Fallow land arises to a minor extent (not shown in Figure 4). A difference lies in the development of agricultural income per person. Whereas it remains more or less constant in the linear programming model it increases steadily in the system dynamics model (see Figure 5). The relative differences in income per person for the four scenarios are similar for both models. The difference in the development of the variable between the two models arises as overall agricultural income declines more than agricultural workforce in the linear programming model. The opposite holds for the system dynamics model. Additionally, due to model structure and the limited level of detail, income in the system dynamics model is rather high in general.

Because the system dynamics model generates almost identical behavior for the four scenarios a general feature of complex systems is confirmed, namely that they resist most policy changes (Forrester 1971 in Richardson 1991, Sterman 2000).

The linear programming model, on the contrary, shows different and also oppositional results for the four scenarios. *New direct payments* as well as *local processing* result in a higher share of dairy cattle than in *base run*. Dairy cattle even increase to 113% of their initial value when *new direct payments* and *local processing* are combined. This is a direct consequence of the income-maximization feature underlying the model: As product prices for milk increase (they increase slightly more than for meat, see Table 4) and as work is subsidized by the new direct payments, the work intensive cattle type (dairy cattle) is chosen. With a decline in land-related payments work extensive areas are abandoned which leads to fallow land of almost 10%.

These results cannot be achieved in the system dynamics model for two reasons. First the system dynamics model is a simulation and not an optimization model. Second, in the *new direct payments* scenario the change in the payment scheme occurs from year 8 to 12. By this time, however, some persons have already left agriculture and the change in livestock from dairy to nursing cattle has well proceeded. We find here an example of path-dependency. Those persons that have left agriculture will not return as they have undergone re-education, found a job elsewhere in the regional economy or emigrated from the region. The same holds for livestock. Once the stables for dairy cattle are converted into stables for nursing cattle, this process will not be reversed. The desired effects of the new direct payments scheme can therefore not set in. This is a crucial result from model comparisons and will be discussed further in the conclusions.

Figure 5: Income development in the system dynamics model for the four scenarios



6 Conclusions

In this paper we compared policy and outcome contrasts of a linear programming model and a system dynamics model. The models were both applied to the question of the effects of structural change in Swiss mountain agriculture on regional land use, agricultural employment and agricultural income. We studied different policy measures in order to analyze model behavior and policy implications of model results. We thus aimed at identifying and differentiating the suitability of the two model types for decision support.

From the methodical comparison of the two models conclusions can be drawn as to which and whose questions can be asked to the models:

- The linear programming model generates information on the development of the agricultural sector as a reaction to changes in economic, social or political conditions. It is therefore especially suited as a decision support tool for policy makers elaborating national policy concepts and optimal sectoral policy measures for given goals.
- The system dynamics model is most useful in a specific region. It is valuable in regional and endogenous development initiatives as a communication tool and provides local and regional decision makers with holistic understanding of the crucial factors affecting regional rural development in the long run. It helps deciding on the effectiveness of additional local and regional measures for specific development strategies given the overall sectoral development. A system dynamics model is also suited as a decision support tool for the regionally adapted implementation of national policy concepts and of sectoral policy measures.

In addition to the methodical comparison, the comparison of model results for the different policy scenarios allows conclusions as to what answers can be queried from the models if they are applied to the same questions. The analysis of the effects of alternative policy scenarios showed that different results and thus different policy implications are generated if the policy measure includes a structural break. This could be observed with the new direct payment scheme (combined with local processing) that was tested for the goal of maintaining dairy farming and thus agricultural employment in mountain areas. In this case, the policy recommendation drawn from the linear programming would be to subsidize agricultural workforce. The system dynamics model identified the change in livestock from dairy to nursing cattle as a path-dependent process triggered mainly by product price signals. The policy recommendation would consequently be to stabilize dairy farming via milk price.

It is therefore advisable to combine the two model types for decision support in applied research. The linear programming model specifies optimal future structures for a given policy goal. Whether these can at all be achieved is answered by the system dynamics model. It identifies the path-dependent processes that influence the effectiveness and efficiency of optimal policy measures and provides the information necessary for a successful communication and implementation of the measures.

Even if the models are not combined in practical application, both modeling approaches can profit from each other. The benefit of a linear programming model for the elaboration of a system dynamics model is accurate information on the overall development challenges faced by the regional system. These challenges are subsequently addressed by the system dynamics model so that the constraint of restricted precision can be considerably alleviated. The benefits of a system dynamics model for a linear programming model, on the other hand, lie most of all in the coverage of the adaptation processes and in the identification of path-dependencies. Another important benefit is that the purely quantitative economic model can be expanded by the qualitative variables included in the system dynamics model.

Acknowledgements

We are grateful to Kurt Zgraggen for his valuable suggestions and to three anonymous reviewers for helpful comments.

References

Barlas Y. 1996. Formal aspects of model validity and validation in system dynamics. *System Dynamics Review* **12** (3): 183-210.

Barlas Y., Çirak K., Duman E 1996. Dynamic simulation for strategic insurance management. *System Dynamics Review* **16** (1): 43-58.

Bouman B. A. M., Jansen H. G. P., Schipper R. A., Nieuwenhuyse A., Hengsdijk H., Bouma J., 1999. A framework for integrated biophysical and economic land use analysis at different scales. *Agriculture, Ecosystems and Environment* **75**: (1) 53-73.

Day R.H. 1963. Recursive programming and production response. North-Holland Publishing Co., Amsterdam.

De Haen H. 1971. Dynamisches Regionalmodell der Produktion und Investition in der Landwirtschaft. *Agrarwirtschaft Sonderheft 43*. Alfred Strothe Verlag, Hannover.

Errington A. J. 2000. Rural development and the rural economist. In: Hillebrand H., Goetgeluk R., Hetsen H. (eds.): *Plurality and rurality. The role of the countryside in urbanised regions*. Agricultural Economics Research Institute (LEI), The Hague. Vol. 2/2: 115-128.

Fourer R., Gay D. M., Kernighan B. W. 1993. AMPL. A modeling language for mathematical programming. Body & Fraser, Danvers MA.

Flury C., Gotsch N., Rieder P. 2000. Socio-economic and ecological effects of alternative direct payment regimes on different Swiss Alpine regions. *Cahiers d'Economie et Sociologie Rurales* **57**: 5-26.

Flury C. 2002. Zukunftsfähige Landwirtschaft im Alpenraum - Entwicklung von Nutzungsstrategien für den Kanton Graubünden auf der Basis eines Sektormodells. Wissenschaftsverlag Vauk, Kiel.

Flury C., Rieder P. 2003. Strukturelle Auswirkungen auf das Berggebiet, Folgestudie Umlagerung der Milchpreisstützung, Teil 3, Institut für Agrarwirtschaft, ETH Zürich.

Hazell P. B. R., Norton R. D. 1986. Mathematical programming for economic analysis in agriculture. MacMillan Publishing Company, New York.

Johnson G. L., Quance C. L. 1972. The overproduction trap in U.S. agriculture. A study of resource allocation from World War I to the late 1960's. Resources for the Future, Inc., Washington D.C.

Keusch A. 2000. Modellierung ressourcenökonomischer Fragestellungen am Beispiel der Erosion im Gebiet des Baldeggersees. PhD dissertation, ETH Zürich.

Kopainsky B., Buchli S., Rieder P. 2003. How peripheral and agrarian communities work and how their viability can be improved – insights from a System Dynamics approach. Paper presented at the Regional Studies Association International Conference „Reinventing Regions in a Global Economy", Pisa, April 12-15, 2003. http://www.regional-studies-assoc.ac.uk/events/pisa03/kopainsky.pdf

Richardson G. P. 1991. Feedback thought in social science and systems theory. University of Pennsylvania Press, Philadelphia.

Pannell D. 1997. Practical linear programming. John Wiley &Sons, New York.

SBV (Schweizerischer Bauernverband) 2001. Statistische Erhebungen und Schätzungen über Landwirtschaft und Ernährung. Brugg.

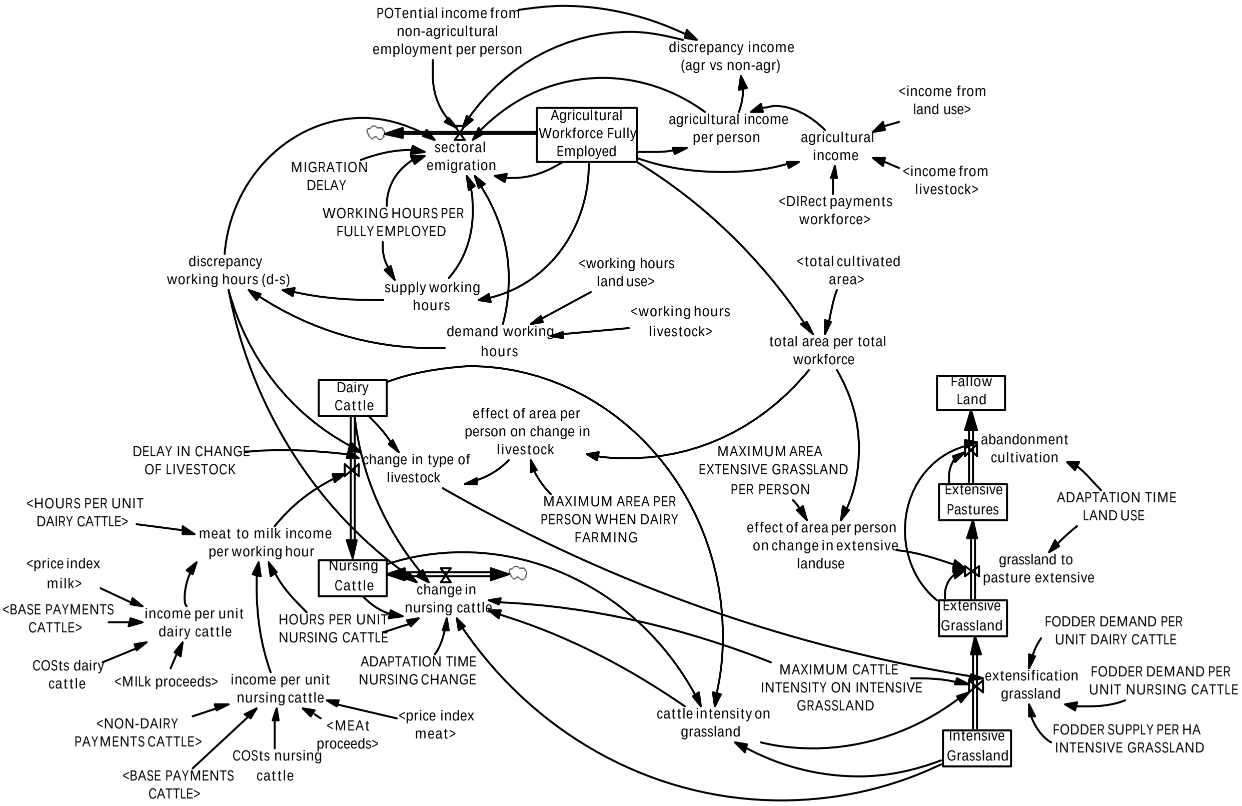
Sterman J. D. 2000. Business Dynamics. Systems thinking and modeling for a complex world. McGraw-Hill, Boston.

Appendix

Appendix 1: Detailed overview of the structure of the linear programming model

		Activity										RHS farm level				RHS sub-regional level			
Level of aggregation	Constraint	Grassland	Arable farming	Cattle and sheep	Purchase of feeding concentrates	Purchase of mineral fertilizer	Purchase and sale of animals	To let and take land on lease	Purchase and sale of labor	Milk quota trade		Milk quota	Family labor	Farm land area		Market for animals	Summering pasture	Farm land area	Market for hired labor
Farm	Land use	x	x					x						x					
	Crop rotation		x																
	Animal feeding	x	x	x	x														
	Fertilization	x	x	x		x													
	Cattle and sheep rearing			x			x												
	Milk production			x						x		x							
	Labor	x	x	x	x	x			x				x						
Community	Market for leased land							x											
	Labor market								x										x
	Land use	x	x															x	
	Summering pasture			x													x		
Sector	Animal trade						x									x			

Appendix 2: Detailed overview of the structure of the system dynamics model (simplified stock flow diagram)



Back to the Top