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Modelling structural-change-related shifts in labour input in the agent-based sector model SWISSland

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Abstract

An empirically-based approach was developed to forecast the use of family labour, external labour, contractors and off-farm work in the agent-based sector model SWISSland. 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, contractors and off-farm work. The optimisation results showed that this method provides detailed forecasts for different labour categories.

Keywords: *agent-based sector model, farm labour input, cluster analysis, structural change, Bayesian networks*

JEL classification: *Q12, Q18, C11, C61*

1. Introduction

The agent-based sector model SWISSland serves as a decision-support system for policy analysis in Switzerland. To date, it has forecast production and investment decisions as well as farm-exit and land-leasing decisions over a period of 18 years, but does not yet allow us to forecast labour input in the context of structural change (Möhring et al., 2011; Mack et al., 2011). Because projections on farm-labour input and off-farm work are also relevant to policy, the aim of this study was to develop and validate an approach for forecasting labour-input processes in the agent-based sector model SWISSland. The SWISSland model uses a non-representative FADN-farm sample from 3400 currently existing family farms as a data source for defining the agent population (Möhring et al., 2010). This database ensures detailed individual farm records for defining the agents' production resources in terms of land use, livestock, family and non-family labour, and off-farm labour in the base year. The SWISSland model forecasts animal- and plant-production decisions, as well as investment decisions on the basis of PMP-based optimisation models (Möhring et al., 2011).
From the literature, we know that off-farm work decisions and the use of family labour, external labour and contractors on the farm are driven by numerous determinants such as farm-structure criteria, individual preferences, market conditions and farm growth (Benjamin and Guyomard, 1994; Beckmann, 1997; Hayami, 2010; Eastwood, 2010). From Beckmann (1997), we are also aware that the use of family labour, external labour and contractors is naturally interdependent. Studies within a wide range of approaches and disciplines have examined characteristics and motivations that explain part-time and full-time farming. Schmitt (1989) pointed out that family labour is deployed off-farm both because some family members have a preference for, or are better qualified for, non-agricultural work, and because the diminishing marginal benefits of employing labour on the family farm make off-farm work more profitable. Benjamin and Guyomard (1994) showed that possessing a higher general education was reflected in higher off-farm labour-market participation of both farm managers and their spouses. The same authors also showed that younger wives were more likely to work off-farm, and that the wife's participation in the off-farm labour market decreases as the number of children in the family increases. The extent to which farm growth leads to changes in labour allocation depends

on productivity and labour capacities on the farm. When productivity remains constant, dynamic farm growth entails a dynamic growth in labour input, i.e. a change in farm size also entails a change in labour input. The theoretical possibility of leaving the ratio between the types of labour at a steady level is not always realistic in the case of growth and shrinkage processes, however. Reasons for a change in the composition of the types of labour accompanying farm growth might be that family labour capacity is already exhausted, or that the critical threshold for employing (additional) external labour has not yet been reached. On the basis of differing flexibility, it is obvious that the variation in working-time requirement can be controlled to especial advantage via the wage labour of and/or for other farms, provided that there is a supply or demand for this.

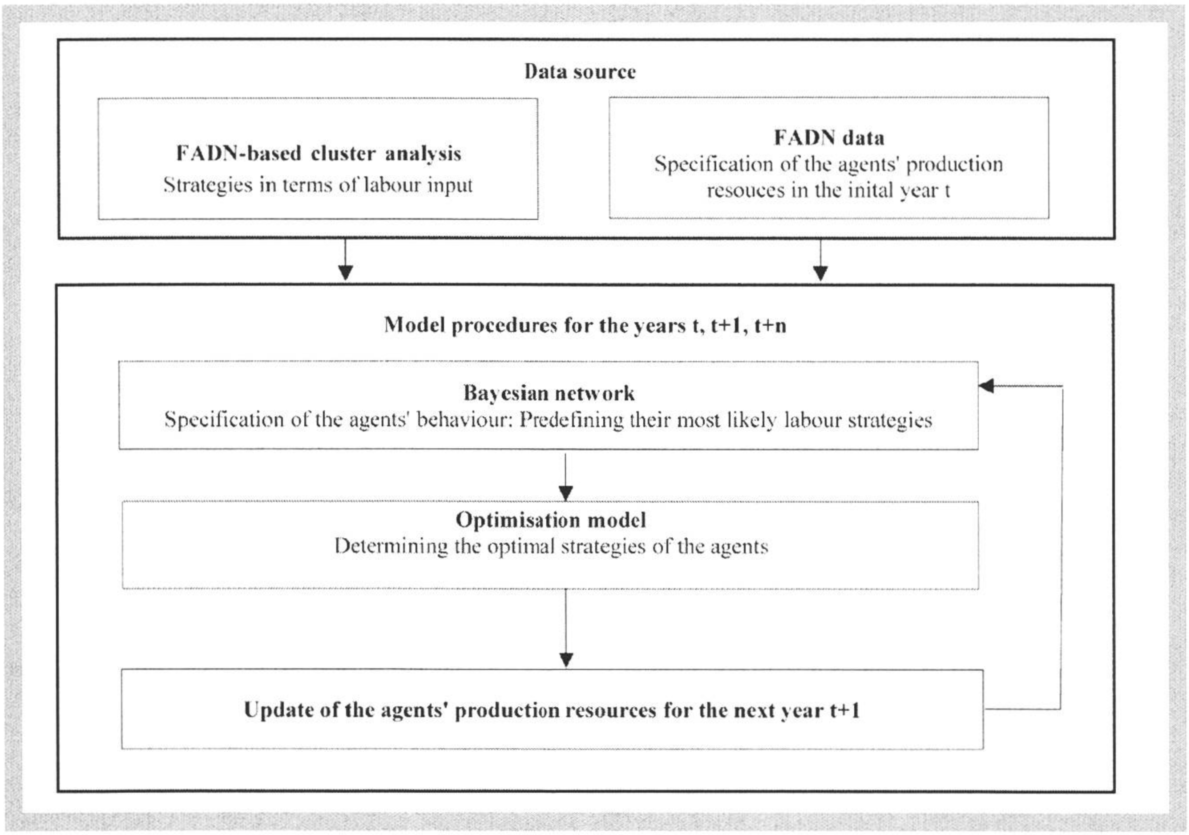
Many agent-based models (Happe, 2004; Stolniuk, 2008; Sahrbacher, 2012) use optimisation approaches which distinguish between family and hired labour only. Farm labour may be hired, and family members may work off-farm. These approaches are mainly driven by costs for hired labour and opportunity costs for family labour, while other strategies are not taken into account. Nevertheless, forecasts of on-farm and off-farm labour-resource allocation, 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, which is why an alternative, empirically based method was developed. This approach is chiefly characterised by the classification of the SWISSland's agent population in terms of their presumed labour-input strategy as a preliminary step in the optimisation process. The subsequent optimisation run then determines the agents' optimal labour strategy based on their most likely labour strategies, market conditions, and growth in farm size. Labour-input strategies capturing the close interdependencies among the use of family labour, external labour, contractors, and off-farm work were therefore derived from empirically observed labour-input shifts on FADN farms.

Section 2 of this paper describes the forecasting procedure in detail, and outlines the model scenarios. The results are described in Section 3, while Section 4 contains a discussion of these results.

2 Methodological approach

In this study, we forecast adjustments in the use of family labour, external labour, contractors and off-farm work in a two-phase procedure, shown in Figure 1. Firstly, we estimate the agents' most likely labour-input strategies based on their production resources, using a Bayesian network for this. Secondly, we determine their optimal labour-input strategies in the optimisation process, subject to the predefined strategies, market conditions, and growth in farm size. Since SWISSland is a recursive-dynamic optimisation model, both routines proceed in annual time steps.

Figure 1: Overview of the model procedures for forecasting labour-input decisions in the agent-based sector model SWISSland



The results of a cluster analysis provided the database for the two-phase procedure. The cluster analysis was carried out to obtain the most common labour-adjustment strategies in Switzerland from empirically observed changes. Cluster results were used to set up the Bayesian network, which serves as the main tool in the first phase of the procedure. The results were also used to parameterise all observed labour strategies in the single-farm optimisation model.

The agents' production resources and farm-structure criteria constituted the main determinants for predefining their probable labour decisions. Because of the non-linear relationship between these variables and the high correlation among them, a Bayesian network was used. Since ongoing optimisation processes could lead to shifts in farm size and labour resources, the agents' behaviour may also change. In order to take account of the dynamics over time, the agent population's most likely labour strategies were determined in annual time steps prior to the optimisation process.

The methodological section below consists of three parts: the first part describes the cluster analysis providing the database for the forecasting procedure; the second part presents the principle of the Bayesian network, and describes the use of the cluster results in setting one up; finally, the third part describes the operationalisation of the labour-adjustment strategies and their incorporation into the agent's optimisation model.

2.1 Cluster analysis

A cluster analysis was carried out to identify a limited number of labour-input strategies – specifically, the most common ones in Swiss agriculture in the past. These formerly predominant strategies were used to classify the agents in terms of their presumed labour-input strategy. Thus, Swiss FADN farms whose family, wage and external-labour inputs changed according to the same pattern from 2004 to 2009 were allocated to groups by means of a cluster analysis. The cluster analysis is known to offer a wealth of methodological starting points influencing both the number and composition of the clusters. Irrespective of the cluster process, however, a cluster solution should have clusters that are as homogeneous as possible, whilst possessing a high level of heterogeneity between the groups and not leading to a completely different cluster solution in the event of slight changes in the dataset (Bacher et al., 2010). The partitioning k-means method was chosen for this study, since it generates homogeneous clusters with the smallest possible variation within the clusters on account of its optimality criteria. The optimal cluster solution cx, where x={1...n}, was determined by a combination of quantitative validation methods and qualitative content checks (Hoop et al., 2013).

A total of 2003 farms which remained in the FADN sample for the period 2004 to 2009 were selected as a cluster database. The Swiss FADN system provides the number of family labour units and external labour units employed on the farm, as well as the number of family labour units working off-farm, in annual working units[1] on a self-disclosure basis. Farm expenditure for labour and machine use by third parties as well as income for labour and machine use on neighbouring farms is also available in the FADN system. These five key accountancy figures formed the underlying data for the cluster process, whose absolute changes from 2004 to 2009 (period t_1) were used as cluster-forming variables. The «k-means» function in the basic R-package (R Development Core Team, 2011) was used for the cluster analysis.

From the cluster analysis, we obtain the common labour strategies for Switzerland in terms of family labour, external labour, wage labour of third parties, wage labour for third parties, and sideline. A distinct strategy c_x is defined by the mean absolute deviation (d_x) of all five cluster-forming variables over the period t_1. In addition, we describe a labour strategy c_x by a set of m underlying-farm-structure variables S_{jx} from period t_0 where j={1...m}, which represents its status before the change. Farm-structure differences between at least two clusters were verified by applying a Kruskal-Wallis Test.

[1] Both family and external labour units are generally recorded in working days, with an annual labour unit (ALU) corresponding to a fully efficient person working on the farm at least 280 working days per annum. A maximum of one annual labour unit can be credited per person. Part-time employees are converted pro rata on the basis of 280 normal working days per year.

2.2 Bayesian network

2.2.1 Theory

Bayesian networks «...capture the believed relation between a set of variables which are relevant to some problem» (NeticaTM). In theoretical terms, they are defined as «Direct Acyclic Graphs (DAGs) where the nodes are random variables and certain independence assumptions hold» (Charniak 1991). Bayesian networks are based on the Bayesian theorem, as well as on the idea of a conditional dependence consisting in a selection of a subset of variables (parents) that influence other variables being investigated (child) (see Charniak, 1991 for more details). Bayesian networks are illustrated by nodes and arcs. Nodes represent the variables, whilst arcs represent the dependence connection between «parent» and «child». A node is referred to as a «parent» because of its influence on a node referred to as a «child». Bayesian networks allow us to calculate the posterior probability distribution under the assumption of the conditional dependence of the nodes in the network, provided that the values of the nodes have been observed in accordance with the Bayesian rule. Bayes' theorem enables us to determine the probability of an event B given event A: when the events are dependent, then the probability P of event B depends on the event A.

When

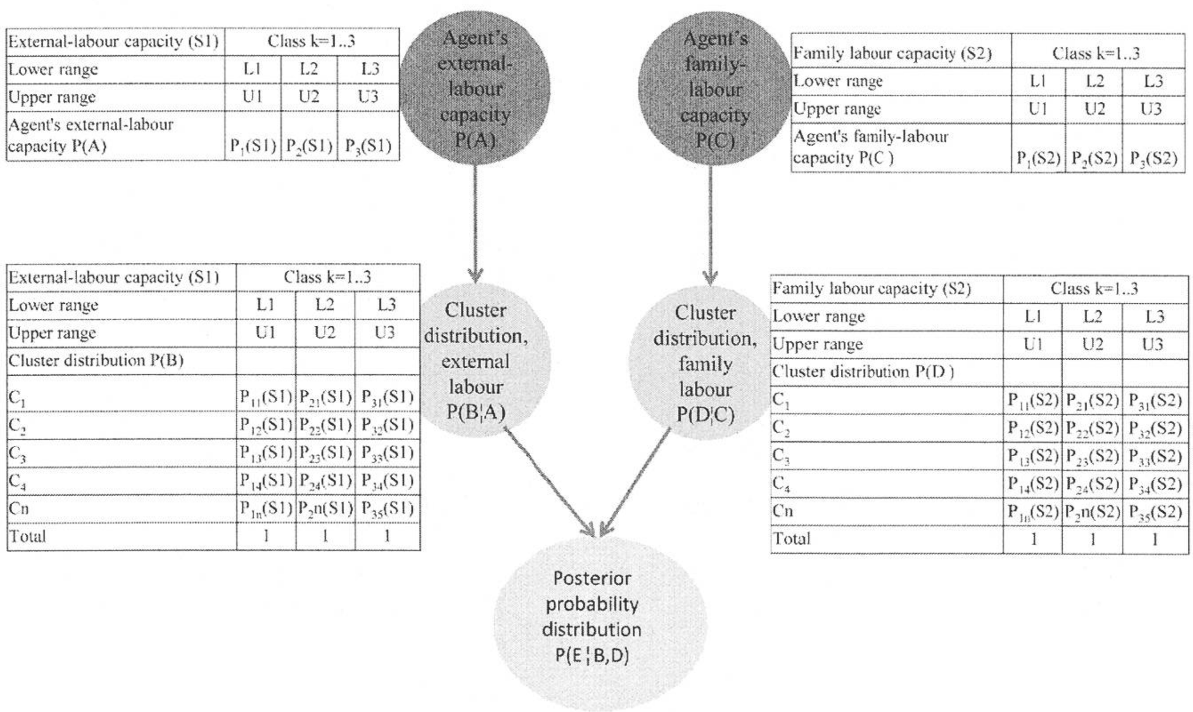
$$\mathrm{par(B) = parent\ node\ of\ B = A;}$$
$$\mathrm{P(B|\ par(B)) = P(B|A) = (\ P(A|B) * P(B))/\ P(A).}$$

2.2.2 Design of the Bayesian networks

We estimated the most likely labour strategies c_x of an agent in the period t_1, based on a set of underlying farm-structure variables S_{jx} from the period t0 for which significant differences between at least two clusters were verified in a Kruskal-Wallis Test.

Each farm-structure variable S_j was represented by a parent node and a child node in the network. Continuous variables S_j were divided into 10 classes which cover the range of the values in the agent population. The agent's specification for variable S_j constituted the parent node, whilst the cluster distribution of S_j derived from the cluster analysis determined the child node. The cluster distribution of a variable S_j was represented by the probability $p_{kx}(S_j)$ of a distinct cluster c_x, bearing in mind that the sum of all probabilities over n clusters is one. An example of a Bayesian network bearing in mind only two farm-structure variables (S_1= external-labour capacity; S_2=family-labour capacity) is demonstrated in figure 2. For both variables, three classes (k=1…3) were distinguished. The agent's external-labour capacity P(A) and his family-labour capacity P(C) represent the parent nodes. The probabilities P(B)=P_{kx}(S1) and P(D)=P_{kx}(S2) of a distinct cluster cx define the child nodes for which P(BI par(B)) = P(BIA) and P(DI par(D)) = P(DIC). For each agent, the Bayesian network calculates the posterior probability distribution P(E) of a distinct cluster.

Figure 2: Design of the Bayesian networks for two farm-structure variables (example).



External-labour capacity (S1)	Class k=1..3		
Lower range	L1	L2	L3
Upper range	U1	U2	U3
Agent's external-labour capacity P(A)	P_1(S1)	P_2(S1)	P_3(S1)

Family labour capacity (S2)	Class k=1..3		
Lower range	L1	L2	L3
Upper range	U1	U2	U3
Agent's family-labour capacity P(C)	P_1(S2)	P_2(S2)	P_3(S2)

External-labour capacity (S1)	Class k=1..3		
Lower range	L1	L2	L3
Upper range	U1	U2	U3
Cluster distribution P(B)			
C_1	P_{11}(S1)	P_{21}(S1)	P_{31}(S1)
C_2	P_{12}(S1)	P_{22}(S1)	P_{32}(S1)
C_3	P_{13}(S1)	P_{23}(S1)	P_{33}(S1)
C_4	P_{14}(S1)	P_{24}(S1)	P_{34}(S1)
Cn	P_{1n}(S1)	P_2n(S1)	P_{35}(S1)
Total	1	1	1

Family labour capacity (S2)	Class k=1..3		
Lower range	L1	L2	L3
Upper range	U1	U2	U3
Cluster distribution P(D)			
C_1	P_{11}(S2)	P_{21}(S2)	P_{31}(S2)
C_2	P_{12}(S2)	P_{22}(S2)	P_{32}(S2)
C_3	P_{13}(S2)	P_{23}(S2)	P_{33}(S2)
C_4	P_{14}(S2)	P_{24}(S2)	P_{34}(S2)
Cn	P_{1n}(S2)	P_2n(S2)	P_{35}(S2)
Total	1	1	1

2.3 The agents' optimisation model

Agents' production and investment decisions, as well as off-farm work decisions and decisions to perform wage labour for a third party were made using a recursive farm-optimisation model predefined by a set of alternative production-decision variables (Table 1). Let us denote alternative production decisions by a non-negative variable block $X_{t,a,i}$, where t (t=1,...,T) denotes the set of time periods, a = (a=1,...,A) the set of agents, and i = (i=1,...,I) the set of production activities, where production activities from 1 to ii are the statistically observed activities in the base year (2008), and those from ii to I are potential new production activities. Because annual variations in land use and livestock numbers were not taken into account, the average of three years (2006–2008) was used as the base year. Labour-adjustment strategies were implemented by a set of alternative labour-decision variables ($N_{t,a,j}$) for j = (i=1,...,J), which defined the extent of changes in family-labour capacity, external-labour capacities, wage labour for third parties and wage labour by third parties within a single time period. These predefined adjustment strategies were determined by the Bayesian network. Apart from these strategies, an agent always had the option of not making any changes (the no-change strategy). Labour-decision variables were restricted to one unit in the optimisation model (see Table 1). 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[2].

[2] These requirements have not yet been implemented in the farm-optimisation models.

Table 1. Modelling labour strategies in SWISSland's single-farm optimisation model

			Production activities $X_{t,a,i}$			Labour activities $N_{t,a,i}$				
			Plant and animal production activities	Leasing of land	Purchased activities	Labour strategy cx1 determined by the Bayesian network	Labour strategy cx2 determined by the Bayesian network	No-change labour strategy		
	Household income	CHF	Objective function coefficients						<=	
Farm capacities	Farm area (FA)	Ha	+	-					<=	RHS
	Food production	Dry matter	-+		-				<=	0
	Housing places	Places							<=	RHS
Labour capacities	Family labour on the farm	ALU	+			+-d	+-d		<=	RHS
	External labour on the farm	ALU	+			+-d	+-d		<=	RHS
	Wage labour by third parties	CHF	+			+-d	+-d		<=	RHS
	Wage labour for third parties	CHF				+-d	+-d		<=	RHS
	Sideline	ALU				+-d	+-d		<=	RHS
	Labour strategies					+	+	+	=	1

+ demand; – supply; RHS: Right-hand-side capacities; d: mean absolute deviation of all five cluster-forming variables. ALU: Annual labour units

One of the main assumptions of the model is that the farm manager's overall objective is to maximise his household income (Z).
This objective function is illustrated as follows:

$$Max\ Z_{t,a} = \sum_i \delta_t r_{t,a,i} X_{t,a,i} + \sum_i p_{t,a,i} X_{t,a,i} - \sum_i v_{t,a,i} X_{t,a,i} + \sum_j w_{t,a,j} N_{t,a,j} - \sum_g s_{t,a,g} L_{t,a,g} - \sum_h q_{t,a,h} Y_{t,a,h} - \sum_i \alpha_{a,i} X_{t,a,i} - 0.5 \sum_i \beta_{a,i} X_{t,a,i}^2$$

The total revenue from the land-use and livestock activities i (i=1,...,I) of agent a in time period t is the product of revenue coefficients r_i, a time-period-specific discount factor δ, and an activity level X_i. The vector of direct payments is represented by pi and the vector of purchased activities by v_i. Income from off-farm activities j (j=1,...,J) is the product of off-farm wages w_j and off-farm activities N_j. The vector of labour cost for employees is s_g (g=1,...,G), while L_g is the level of hired labour. Labour costs are included in the cost function in the form of additional linear elements. The costs for investments in machinery and buildings are calculated as a product of cost coefficients q_h and investment activities Y_h.
Even with a constraint structure and parameters that are theoretically correct for an agent, it is highly unlikely that a pure linear-programming model will calibrate closely to the base-year data of the FADN farm. For this reason, the decision-making process for plant- and livestock-production activities followed the standard Positive Mathematical Programming (PMP) approach (Howitt, 1995). The PMP approach is a suitable method for overcoming this problem and obtaining solutions which are more plausible. In addition, PMP-based models yield smooth responses to exogenous changes (Howitt, 1995).
The FADN farms implemented a certain production programme in the base year. For this observed production programme, PMP terms α and β were estimated based on their individual variable production costs. For the estimate, exogenous elasticities were applied (Gocht, 2005), which in the absence of the exact values for Swiss agriculture were defined as unity. PMP terms could only be estimated for those production activities observed in the base year, and not for potential new production activities. Owing to scarce production resources, management reasons, or market or agricultural-policy conditions, however, farms are usually not able to fully realise all potential production lines that predomi-

nate in a region. To model potential new production activities of the future, we used the average PMP terms from other similar agents that had already carried out this production activity in the base year, whilst increasing the average slope ($\bar{\beta}$) of the marginal cost function by 1.5, assuming that an agent not performing a production activity in the base year would have higher costs than their peers who had already carried out this production activity.
Marginal cost functions (MCs) for observed production activities (X1..ii) in the base year were as follows:

$$MC(X)_{ai} = \alpha_{ai} + \beta_{ai} X_{ai} \qquad for\ i = 1\ldots ii$$

Marginal cost functions (MCs) for potential new production activities ($X_{ii...I}$) in the base year, where $\bar{\alpha}$ and $\bar{\beta}$ are the average of the observed values of similar farms. These groups include farms of similar types in the same regions:

$$MC(X)_i = \bar{\alpha}_i + 1.5 \bullet \bar{\beta}_i X_i \qquad for\ i = ii\ldots I$$

The agents' production yields and revenues (r_i) were derived from their FADN records for all observed production activities ($X_{1..ii}$) in the base year. For potential new production activities ($X_{ii...I}$), we used the corresponding values of similar FADN-farm groups which had already carried out these activities in the base year. We specified the yields and revenues of potential new activities by summing up the average and standard deviation of a similar farm group, while the standard deviation was randomly varied between plus one and minus one for each agent.

2.4 Scenario definitions

Forecasts were carried out for 2008 to 2025. The direct-payment system of the Swiss agricultural policy reform AP 2011, in which general direct payments constituted the bulk of the financial support (78% in 2011), was taken into account for the period up to 2013. General direct payments included animal-unit-based and area-based payments to farmers in the lowland regions, plus additional payments for farmers producing under adverse production conditions in the hill and mountain regions. Ecological direct payments included payments for extensive crop production, ecological compensation areas and organic farming. Furthermore, two animal-welfare programmes were available (El Benni et al., 2011). Farmers could also choose to apply for several ecological direct payments without any regional restrictions (see El Benni and Lehmann, 2010, for details).

For forecasts for 2014 onwards, the Swiss Agricultural Policy for 2014–17, in which all direct payments were linked to aims set out in the Swiss Federal Council's Message on Agricultural Policy for 2014-17 (Federal Council, 2012), were taken into account. Direct payments are spent to ensure the provision of adequate supplies of high-quality food, as well as to preserve the natural heritage, the environment and biodiversity. Single area payments (SAPs) will be the most important payment schemes from 2014 onwards. Single farm payments were also introduced in order to ensure a socially acceptable level of income after implementation of the reform.

Exogenous price and cost trends for the period 2014 to 2017 were derived from Zimmermann et al. (2011). For 2018 onwards, we distinguish two different policy scenarios: a status quo scenario, and a free-trade scenario with the European Union. «Status quo» means that tariffs remain in place for the main agricultural products until 2025. In this case, no further drops in product prices were assumed, while cost trends from the past were extrapolated to 2025. In the event of a free-trade scenario, average price drops of 40–50% were applied from 2018 to 2022 in four steps. It was assumed that most of the costs and wages apart from energy would either remain at 2017 levels or fall slightly.

3. Results

3.1 Cluster-analysis results

The combination of quantitative validation methods and qualitative content checks led to eight clusters. Clusters 1, 2, 3 and 7 were stable, cluster 6 was relatively stable, and clusters 4, 5 and 8 were fairly unstable (Table 2). The eight identified clusters illustrate common shifts in labour-resource allocation that are typical for agriculture in Switzerland, over a period of five years (Table 2). More than half of all the farms belong to cluster 1, in which family, wage and external labour both on-farm and off-farm have hardly changed over five years.

Owing to its relatively stable organization of work, this will hereinafter be referred to as the «stable» cluster.

In the second cluster, family labour units significantly restricted their sideline activities, but only partially in favour of farm activities. This cluster, which contains only 5% of the farms, was termed «sideline dropouts». By contrast, the defining characteristic of cluster 3 was that its family workforce increasingly pursued a sideline at the expense of farm activities. This cluster was downsizing its farm, which distinguished it significantly from clusters 1 and 2. Representing 8% of all farms, cluster 3 was described as the «sideline-oriented» cluster.

Table 2: Results of the cluster analysis: Changes in labour input from 2004 to 2009

		Cluster c_x							
		No change	Change strategy						
		C_1 **Stable**	C_2 **Sideline dropout**	C_3 **Sideline-oriented**	C_4 **Family labour-focused**	C_5 **External labour-focused**	C_6 **Outsourcing-focused**	C_7 **Wage-labour supplier**	C_8 **Wage-labour dropout**
No. of farms	No.	1035	104	160	297	175	124	60	45
Distribution	%	52%	5%	8%	15%	9%	6%	3%	2%
Cluster-forming variables d_{jx} (mean absolute deviation t_1 = 2004-2009)									
Family labour on farm	ALU	-0.03	0.20	-0.22	0.44	-0.37	-0.01	-0.08	0.10
External labour on farm	ALU	-0.03	-0.06	0.01	-0.19	0.67	-0.09	0.09	-0.07
Wage labour by third parties	CHF	307	1748	491	46	810.31	13789.31	1354	816.35
Wage labour for third parties	CHF	451	735	315	569	-151.59	490	26074.56	-20416.58
Sideline	ALU	-0.01	-0.54	0.38	-0.03	-0.02	0.01	0.01	0.05
Farm-structure variables Sjx (mean absolute deviation t_1 = 2004-2009)									
Livestock population	LU	1.6	3.5	1.4	2.6	3.8	7.6	1.9	4.5
	SG[1)]	cd	bcd	d	bc	ab	a	abcd	abcd
Area	UAA	0.3	1.3	-0.1	0.8	1.2	3.1	0.3	1.9
	SG[1)]	b	ab	b	b	ab	a	ab	ab

Fields highlighted in grey: The mean of the cluster deviates more than one cluster standard deviation from the mean of all farms (positive/negative). Underlined digits: The mean of the cluster deviates more than one-half cluster standard deviation from the mean of all farms (positive/negative). ALU: annual labour unit.

[1)] *Significance group (SG). According to the pairwise Kruskal-Wallis test (1952), if two clusters do not have the same letters in their group name, there exists a significant difference between these clusters (P < 0.05, P-value adjustment according to Holm, 1979).*

Table 3: Results of the cluster analysis: Farm structure in 2004

		Cluster c_x							
		No change	Change strategy						
		C_1 Stable	C_2 Sideline dropout	C_3 Sideline-oriented	C_4 Family labour-focused	C_5 External labour-focused	C_6 Outsourcing-focused	C_7 Wage-labour supplier	C_8 Wage-labour dropout
		Farm-structure variables S_{jx} (mean in t_0 = 2004)							
Family labour on farm	ALU	1.28	1.01	1.29	1.17	1.56	1.26	1.40	1.28
	SG[1)]	b	d	b	c	a	bc	b	bc
External labour on farm	ALU	0.29	0.44	0.28	0.46	0.37	0.62	0.42	0.52
	SG[1)]	d	abc	cd	b	bc	a	bcd	ab
Wage labour by third parties	CHF	6857	8420	7260	7478	10511	10936	9302	14264
	SG[1)]	c	bc	bc	c	ab	a	abc	a
Wage labour for third parties	CHF	3653	4358	2837	3486	5185	6392	12477	35113
	SG[1)]	e	cde	e	de	cd	c	b	a
Sideline	ALU	0.17	0.68	0.20	0.20	0.17	0.11	0.17	0.16
	SG[1)]	bc	a	b	b	bc	c	bc	bc
Livestock population	LU	25.25	23.5	25.2	26.7	30.3	34.9	25.5	32.2
	SG[1)]	c	bc	bc	bc	b	a	bc	abc
Area	UAA	19.44	21.0	18.3	20.1	23.8	24.4	22.6	25.2
	SG[1)]	c	bc	c	c	ab	a	abc	a
Open arable land	UAA	4.09	6.1	3.6	4.1	6.4	7.9	6.0	9.3
	SG[1)]	b	ab	b	b	a	a	ab	a

Fields highlighted in grey: The mean of the cluster deviates more than one cluster standard deviation from the mean of all farms (positive/negative). Underlined digits: The mean of the cluster deviates more than one-half cluster standard deviation from the mean of all farms (positive/negative). ALU: annual labour unit.

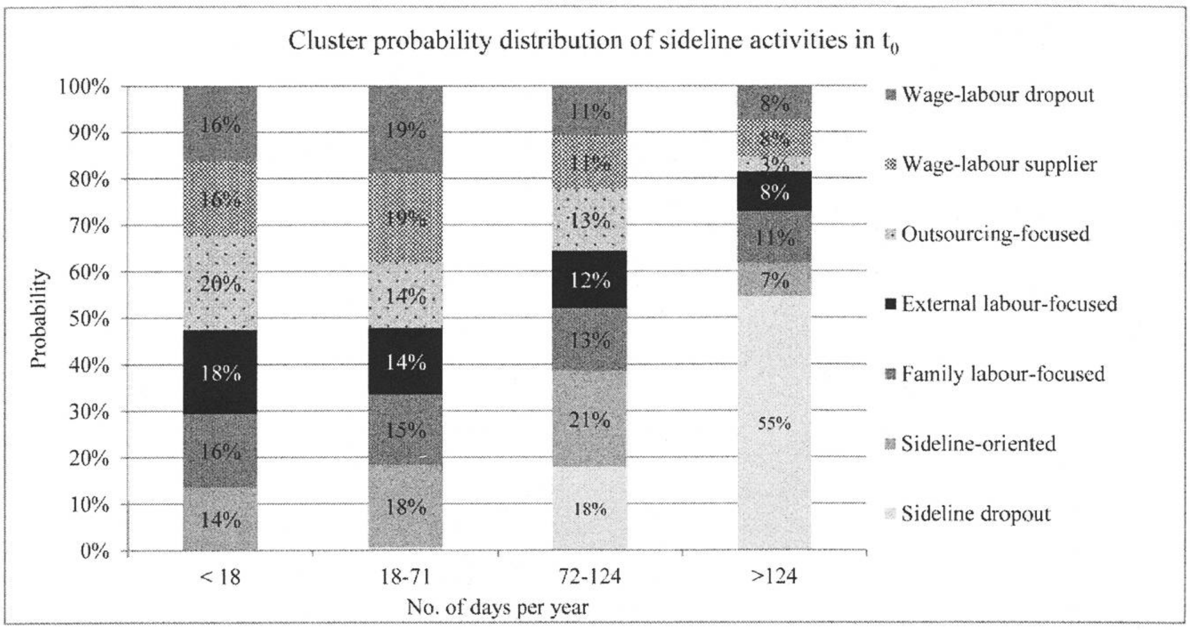
1) Significance group (SG). According to the pairwise Kruskal-Wallis test (1952), if two clusters do not have the same letters in their group name, there exists a significant difference between these clusters ($P < 0.05$, P-value adjustment according to Holm, 1979).

Between 2004 and 2009, «Family labour-focused» cluster 4 employed significantly more family members than the average, while at the same time reducing its workforce expenditure. Cluster 5, the «external labour-focused» farms, employed significantly more external labour between 2004 and 2009 than the average, both in order to cope with the above-average increase in the volume of work and to relieve some of the pressure on the family workforce. A defining characteristic of «external labour-focused» farms is that they employed an above-average number of family labour units up to 2004. Taken altogether, they represent 9% of all farms.

Cluster 6, the «outsourcing-focused» cluster, exhibited above-average growth between 2004 and 2009, making increasing use of agricultural contractors to accomplish this. Only 3% of all farms belong to cluster 7. These farms perform significantly more wage labour for third parties, thereby achieving average

additional revenues of CHF 26,075. As early as 2004, the «wage-labour suppliers» cluster showed a high use of family labour, as well as above-average revenue from wage labour. As a result, the para-agricultural sector was not relaunched, but rather further expanded, whilst the size of other sectors was steadily expanded. Unused capacity reserves, e.g. where the farms have limited growth opportunities, are thus turned to good account.
In Cluster 8, by contrast, the para-agricultural branch «wage labour for third parties» was reduced in favour of other branches. This cluster therefore unites the «wage-labour dropouts». In 2004, the «wage-labour dropouts» cluster was characterised by comparatively high wage-labour revenue, ample land, high use of external labour, and an above-average agricultural income. This indicates that at the start of the period under investigation, these farms were faced with an impending decision regarding growth. Utilisation of the available labour and machine capacity now occurs on their own farm.
The farm-structure variables S_{jx} from period t_0, displayed in Table 3, were used to set up the Bayesian network structure. In addition, geographical location (region), biographical data (age and education of the farm operator) and farm-type criteria were included. The network consists of 14 variables in total. Figure 3 illustrates the cluster probability distribution of the variable «sideline» before the change.

Figure 3: Cluster probability distribution of the variable «sideline» before the change



3.2 Classification results of the Bayesian network

We assumed that all agents could implement the no-change strategy over the entire forecast period, i.e. that the no-change strategy represented the first modelling option. In addition, the results of the Bayesian network were used to define the most likely change strategy as one agent's second and/or third modelling options. Because we did not know the extent to which the number of options influenced the model results, we compared two alternatives. Apart from the «no change» strategy, alternative A1 considered just one additional change strategy for each agent, which represents the highest-probability strategy in the Bayesian networks, while option A2 considered the two most likely change strategies apart from no change. The distribution of the most likely change strategies in the agent population resulting from the Bayesian network for A1 and A2 is displayed in Table 4. Although the base year of the SWISSland model does not correspond to the time period of the cluster results, we compare and discuss the results of the Bayesian network in the two subsequent time periods with the cluster distribution. It is obvious that the «sideline dropout» strategy is greatly overestimated for alternative A1, while the «family labour-focused» strategy is underestimated in the agent population. By contrast, the classification process of alternative A2 leads to an overestimation of the «wage-labour supplier' and «wage-labour dropout» options.

Table 4: Bayesian network results: Frequency of the most likely labour-adjustment strategies in the agent population for alternatives A1 (one change option) and A2 (two change options)

	Cluster results	Most likely labour-adjustment strategies in the agent population before the optimisation process[1]			
		A1		A2	
Change strategy	2004-2009	2008-2012	2013-2017	2008-2012	2013-2017
Sideline dropout	11%	31.4%	35.7%	20%	24.3%
Sideline-oriented	17%	7.8%	4.8%	13%	10.1%
Family labour-focused	31%	3.3%	2.6%	11%	9.1%
External labour-focused	18%	18.7%	19.1%	18%	17.8%
Outsourcing-focused	13%	20.5%	21.1%	18%	18.1%
Wage-labour supplier	6%	6.8%	5.0%	10%	9.0%
Wage-labour dropout	5%	11.7%	11.6%	11%	11.6%

[1] *In addition, we assume that all agents were able to implement the no-change strategy in the forecast period.*

3.3 Optimisation results

The optimal labour-adjustment strategies for the period from the implementation of the optimisation process until 2017 were compared and validated with observed trends obtained from the cluster analysis in the period 2004–2009. The influence of the classification results on the optimal labour strategy is shown in Table 5, which displays the percentage of agents performing at least one unit of a labour- adjustment activity within the time period (see Table 1). Over the two time periods, no agent drops out of the sideline owing to loss of off-farm income. The optimisation results show that the number of «sideline-oriented» agents depends mainly on the classification results. If the agents have only one change option apart from the no-change option (A1), the number of «sideline-oriented» agents is substantially lower than the number of observed «sideline-oriented» FADN farms, whilst «sideline-oriented» agents are more frequent where there are two change options (A2). Furthermore, Table 5 shows that the number of «sideline-oriented» agents is much higher in the first time period than in the second. Whereas «external labour-focused» agents are less frequent in both time periods than empirically observed, the numbers of «outsourcing-focused» agents are in line with the results from the cluster analysis. Both «wage-labour supply» agents and «wage labour dropout» agents are overestimated.

Table 5: Frequency of optimal labour-change strategies in the agent population for alternatives A1 (one change option) and A2 (two change options) until 2017

	Empirical cluster results	Percentage of agents performing at least one unit of a strategy in the first two time periods			
		A1		A2	
Strategy	2004-2009	2008-2012	2013-2017	2008-2012	2013-2017
Stable/No change	52%	75.2%	85.9%	33%	62.3%
Sideline dropout	5%	0.1%	0.0%	0%	0.0%
Sideline-oriented	8%	4.7%	1.0%	14%	2.7%
Family labour-focused	15%	4.0%	0.1%	18%	2.7%
External labour-focused	9%	1.0%	1.5%	2%	4.3%
Outsourcing-focused	6%	5.5%	5.5%	9%	7.2%
Wage-labour supplier	3%	8.2%	6.1%	19%	15.3%
Wage-labour dropout	2%	1.2%	0.0%	5%	5.6%

Table 6 shows the influence of the policy scenario on the optimisation results. In the case of substantial falls in price, outsourcing strategies and para-agricultural branches become increasingly important, whilst sideline-oriented strategies for offsetting income loss hardly increase.

Table 6: Optimisation results: Frequency of labour-change strategies among the agent population for alternatives A1 (one change option) and A2 (two change options) from 2018- 2025

	Optimisation results: Percentage of agents performing at least one unit of a strategy from 2018 - 2025			
	A1		A2	
Strategy	Status quo	Free trade	Status quo	Free trade
Stable/No change	85.81%	61.44%	77.65%	56.89%
Sideline dropout	0.00%	0.00%	0.00%	0.00%
Sideline-oriented	1.12%	2.07%	1.09%	2.44%
Family labour-focused	0.20%	2.36%	1.12%	1.92%
External labour-focused	1.53%	4.69%	3.23%	3.91%
Outsourcing-focused	5.58%	7.65%	4.66%	12.57%
Wage-labour supplier	5.75%	14.91%	8.40%	14.69%
Wage-labour dropout	0.00%	6.87%	3.84%	7.57%

Figure 4 illustrates the forecast for both farm-labour input and off-farm work for the Swiss agricultural sector up to 2025. The results show that the decline in the total number of farms as well as the reduction in family labour and external labour in Swiss agriculture are both driven by structural change. Contrary to these trends, total (deflated) expenses for outsourcing increase by almost 20%, and off-farm work remains at the baseline level or rises by 20% until 2025. At farm scale, average expenditure on contractors actually increases by 40%, whilst the average off-farm labour input rises by 20% in A1 to 50% in A2. The rise in off-farm labour input at farm scale is driven partly by farm sample effects, which are related to structural change, and partly by sideline-oriented agents. Figure 5 shows the extent to which agents' options for labour change influence forecasts on farm income. More than one option for change (A2) delays structural change slightly, as well as increasing average household income by 14%. Higher revenues from para-agricultural branches and lower external-labour costs cause average farm income to increase by 12%.

Figure 4: Swiss agricultural labour-input forecasts for alternatives A1 (one change option) and A2 (two change options) from 2008–2025

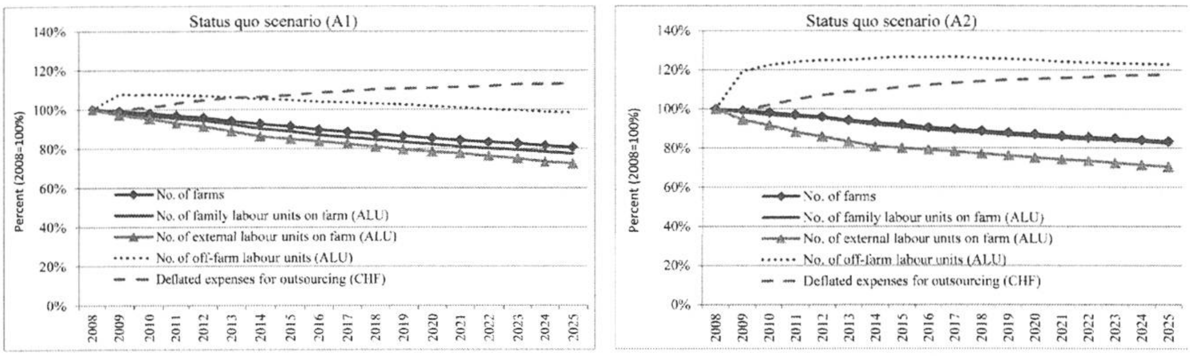
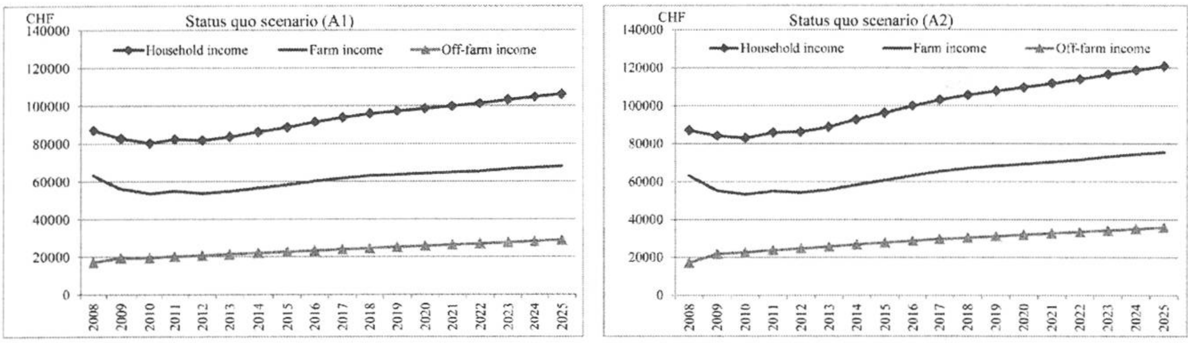


Figure 5: Forecasts of income at farm scale for alternatives A1 (one change option) and A2 (two change options) from 2008–2025



4. Discussion and conclusion

This study employs a two-phase procedure to forecast adjustments in the use of family labour, external labour, contractors and off-farm work. In the first phase, a Bayesian network is used to estimate agents' most likely labour-input strategies based on their production resources. In the second phase, we determine agents' optimal labour-input strategies in the optimisation process subject to the predefined strategies, market conditions and growth in farm size. As SWISSland is a recursive-dynamic optimisation model, both routines proceed in annual time steps.

A cluster analysis was used to select the most common-labour adjustment strategies of Swiss farms. The distinct clusters highlighted the interdependencies among family labour, external labour, contractors, and off-farm work. Furthermore, these adjustment strategies were straightforward to incorporate in the optimisation model. One of the main difficulties lay in assessing the economic benefit of reducing family labour on the farm in order to have more leisure, pursue hobbies or raise children in the «sideline dropout» and «external labour-oriented» strategies within the objective function of the optimisation model. The optimisation results for the «sideline dropout» and «external labour-oriented» strategies, both of which reduce family labour, demonstrate that we have underestimated this benefit to date.

The classification results lead to an under- or overestimation of distinct strategies. What is needed are tests with further farm-structure criteria leading to a better distribution of the strategies in the agent population. The optimisation results demonstrate that the agents' options for labour change influence farm-income forecasts. Being restricted to a single labour-change option limits the agents' ability to adapt in the event of a radical policy change for all agents.

The SWISSland results demonstrate that this method provides sophisticated forecasts for different labour- input categories, making it a potential alternative to pure optimisation approaches in which labour can only be hired and farm family members can work off-farm (Happe, 2004; Stolniuk, 2008; Sahrbacher, 2012). Whilst these approaches are mainly driven by costs for hired labour and opportunity costs for family labour, other strategies are not taken into account for farm agents.

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