Stochastic utility-efficient programming of organic dairy farms[*]

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Abstract

Opportunities to make sequential decisions and adjust activities as a season progresses and more information becomes available characterise the farm management process. In this paper, we present a discrete stochastic two-stage utility efficient programming model of organic dairy farms, which includes risk aversion in the decision maker's objective function as well as both embedded risk (stochastic programming with recourse) and non-embedded risk (stochastic programming without recourse). Historical farm accountancy data and subjective judgements were combined to assess the nature of the uncertainty that affects the possible consequences of the decisions. The programming model was used within a stochastic dominance framework to examine optimal strategies in organic dairy systems in Norway.

Keywords: Agriculture; Risk analysis; Stochastic programming; Stochastic dominance; Organic farming

1. Introduction

In stochastic programming some of the data elements incorporated into the objective function or constraints are uncertain (Kall and Wallace, 1994; Dupačová, 2002). Many mathematical programming studies including risk in agricultural economics have adopted a static framework and included risk aversion in the decision maker's objective function. The most widely used techniques have been quadratic risk programming (Markowitz, 1952; Freund, 1956) and its linear approximations such as MOTAD (Hazell, 1971). For the farmer, the main issue raised by variability of price and production is how to respond tactically and dynamically to opportunities or threats to generate additional income or to avoid losses (i.e., how to respond after the outcome of a random variable is observed) (Pannell et al., 2000). Some studies of conventional farming systems have used stochastic programming with recourse to deal with this aspect (e.g., Kaiser and Apland, 1989; Kingwell, 1994; Torkamani and Hardaker, 1996; Pannell and Nordblom, 1998; Lien and Hardaker, 2001; Torkamani, 2005).

Compared to conventional farming, organic farming systems are subject to different and perhaps higher exposure to risk due to restrictions on use of pesticides, soluble mineral fertilizers, synthetic medicines, purchase of feeds and livestock, etc. Additionally, smaller organic markets may mean greater price fluctuations. But, as far as we know, only deterministic linear programs have been used as decision support models for organic farmers (e.g., Berentsen et al., 1998; Pacini et al., 2004).

In this paper we present a stochastic utility-efficient programming model of organic dairy farms. The model is applied to a Norwegian case farm to examine optimal farming systems under prevailing economic conditions, as well as under a constructed scenario with greater farm income variability. Compared to previous studies, the model includes two methodological advances:

- An organic dairy system is modelled in a whole-farm context that includes risk aversion in the decision maker's objective function as well as both embedded risk (stochastic programming with recourse) and non-embedded risk (stochastic programming without recourse).
- It illustrates how a stochastic programming model can be used within a stochastic efficiency framework (Hardaker et al., 2004b) to rank risky farm strategies and assess policy questions under risk.

2. The model

Our two-stage model incorporates both non-embedded risk and embedded risk, as outlined in Fig. 1. We assume a one-year plan starting in spring. First-stage decisions are, e.g., how many cows and heifers to keep, allocation of land to various crops, and the use of manure from the previous indoor season. The nature of biological production implies yield uncertainty. Since dairy farmers do not perceive milk yield as an important source of risk (Flaten et al., 2005) and because of strict rules about livestock trade in organic farming, possible adjustment to cow numbers etc. to match the milk quota, is not included in the model. Therefore, once the numbers of cows and heifers are decided, the dairy herd size is fixed. The risk associated with the dairy herd is thus non-embedded risk, as indicated by the upper branch of Fig. 1.

[Fig. 1 about here]

Uncontrollable factors (weather, pests, unpredictable biological processes, etc.) imply crop yield uncertainty, with the actual yields being known only after harvest. Hence in the spring time the farmer is uncertain about the area of forage and grain needed to produce the necessary feed for the livestock. However, some decisions can be postponed until better information is available. Although adjustments can be made at any time, we assume for simplicity that the farmer will do the necessary adjustment only once during the year, in mid September. At that time, the type of crop growing season will be known, the grazing season is completed and the herd's indoor-season starts. The second-stage decisions allow us to model a response to the observed crop yields outcome. One set of second-stage (recourse) variables for each state of crop yields outcome is defined. Depending on earlier decisions and the seasonal condition, feedstuffs can be sold or purchased. Bulls can be sold or retained. The possibility to adjust the farm plan in response to uncertain intermediate outcomes of crop yields creates a case of embedded risk, as illustrated in the lower branch of Fig. 1. Embedded risk is modelled using discrete stochastic programming (Cocks, 1968; Rae, 1971).

In a multi-stage decision problem, the later strategies need to be present in sufficient detail to ensure "correct" first stage decisions. Actual later stage decisions can be resolved by running further more refined models incorporating the outcomes of uncertain events as they unfold (Kaiser and Apland, 1989). With this in mind, it was decided to model forage yield uncertainty with only three outcomes and the same for grain yield uncertainty.

2.1. Farmers' behaviour and risk preferences

We use the expected utility model (which has expected profit maximization as a special case) as a normative model of farmers' behaviour under risk. We assume that farmers are risk-averse (or risk-neutral) and that beliefs and preferences vary between farmers. Many programming approaches for whole-farm system planning under risk aversion are available (Hardaker et al., 2004a: Ch. 9). For our problem we use utility-efficient programming (UEP) (Patten at al., 1988), a method which needs little information about farmers' risk attitudes. Because we assume that farmers are usually risk-averse, we are restricted to using a concave form of the utility function, i.e., $U''(z) < 0$, where z is net incomes by state. We used the negative exponential function:

$$U = 1 - \exp(-r \times z) \quad (1)$$

where r is a non-negative parameter representing the coefficient of absolute risk aversion, $U'(z) > 0$, and $U''(z) < 0$. This function exhibits constant absolute risk aversion (CARA), which is a reasonable approximation to the real but unknown utility function for wealth for variations in transitory (annual) income (Hardaker et al., 2004b).

2.2. Activities and constraints

The main groups of activities in the model are as follows (first or second stage variables in parentheses):

1. Forage production activities: pasture and cutting areas (stage 1). Grass-clover from cutting areas is conserved as silage for the 255-days indoor season. For both pasture and silage areas four levels of manure application are distinguished (from 0 to 30 tonnes per hectare (t/ha) pasture and from 10 to 40 t/ha silage). Forage yields respond to manure applications, but at a diminishing rate. Protein content is not affected.
2. Grain production activities (stage 1). Barley can be produced at four levels of manure application (from 10 to 40 t/ha). Further, the grass-clover swards are established under-sown in barley, distinguished by the same four levels of manure application. Grain yields respond to manure applications, but at a diminishing rate. Protein content is not affected.
3. Land and manure activities (stage 1). Organically managed land can be rented at a fixed price (NOK (Norwegian kroner) 1500 per ha, €1≈NOK 8.00). Conventionally produced cattle manure can be purchased (NOK 50 per tonne).
4. Forage trade and transfer activities (stage 1 and 2). Surplus grass from grazing fields can be conserved as silage to be used in winter-feeding. One activity for selling and one for purchasing organic silage are available in stage 2. The output of silage to provide the herd with enough forage during the winter period is maintained through three transfer activities, one for each of the livestock categories (dairy cows, heifers, bulls).
5. Concentrates and grain trading activities (stage 1 and 2). Two mixtures of organic concentrate supplements, with different protein contents, can be purchased. In addition, one mixture of conventional origin was allowed (until August 2005). The mixtures are available in both stages.

In stage 2, organic barley can be sold or purchased. Home-processed barley can be used as concentrate feed in stage 2.

6. Livestock activities: dairy cows, heifer and beef activities (stage 1 and 2). Cows calve in the middle of May. Livestock are given free access to forage, pasture in stage 1 and silage in stage 2. Five actual milk yield levels are assumed (from 4000 to 7000 kg milk per cow per year). Higher milk yields are achieved through addition of concentrates, which depress forage intake. Some heifer calves are raised on the farm to replace cows, while the rest are sold at a few weeks old. Heifers follow a standard rearing system, calving at two years age. In stage 1, bull calves can either be sold or kept over the grazing season. At stage 2, remaining bull calves can be sold immediately or be fed over the indoor season and sold as yearlings.
7. Labour activities (stage 1 and 2). Activities expressing the farm family's opportunity cost of labour or off-farm work are included. Provision is made to hire additional labour.
8. Public payment schemes (stage 1 and 2). The prevailing payment schemes (2003/2004) in Norway are included. The schemes are paid per livestock head or per hectare, with rates varying according to crops and type of livestock. Rates are highest for the first hectares and heads. Specific livestock and area payments offered for organic farming are included.

Generally, the technical responses and relationships were built on a large number of sources. Input prices and rates in the payments schemes were taken from NILF (2003).

The main groups of constraints are as follows:

1. Land constraints (stage 1). Own farmland resources are restricted. A limit is included on the amount of land that can be rented.
2. Rotational limits (stage 1). To avoid the build-up of pests and diseases and to have a balance between fertility-building grass-clover leys and exploitative grains, no more than 50% of the area can be cropped for grain. Another constraint ensures that the ley lasts for exactly three years (the sowing year excluded).

3. Milk quota constraint (stage 1). An annual milk quota is included. No possibilities to acquire additional quota are assumed. Production above the quota has no commercial value.
4. Manure allocation and legislation (stage 1). One constraint ensures that manure used in the crops cannot exceed manure produced on the farm and purchased. There are two organic manure legislation constraints (Debio, 2003). The total amount of manure applied on the holding cannot exceed 140 kg of Nitrogen per year/ha of farmland used. Of this manure, up to 80 kg of Nitrogen per year/ha can be conventionally produced.
5. Dairy herd replacement control and birth balances (stage 1). A replacement constraint ensures that the necessary cows will be provided through rearing replacements (30% culling rate). Two birth balance constraints (one per gender) require that the number of calves sold, bulls sold and heifers reared do not exceed the number of calves produced (one per cow per year).
6. Livestock housing requirement (stage 2). Each category of animal requires a minimum surface area for indoor housing (Debio, 2003). The herd's use of surface area cannot exceed the capacity of the free-range livestock shed (230 m^2).
7. Livestock density (stage 2). One constraint ensures that a maximum number of livestock per ha is not exceeded (Debio, 2003).
8. Labour constraints (stage 1 and 2). On dairy farms, labour needs through the year are quite stable. Just one constraint on an annual basis is then adequate to ensure that labour demand does not exceed the supply from family and hired workers. The labour requirements of many jobs are not directly allocable to specific production activities ('overhead' labour). The constraint 'supply of family labour available to production activities' (variable labour, 1500 hours) equals total family labour supply (3500 hours) less overhead labour (2000 hours). The input-output coefficients for variable labour requirements per unit of the activities are assumed to be constant, irrespective of the scale on which the activities are conducted.
9. Public payment constraints linked to payment intervals for hectares or heads in the various support schemes (stage 1 and 2).

10. Fodder production and utilisation (stage 2). Fodder sold and used in livestock production cannot exceed fodder produced (revealed after stage 1) and purchased. There is one constraint for each of pasture, silage and barley.
11. Feeding requirements (stage 1 and 2). Livestock feeding requirements are specified in minimum dry matter requirements of concentrates and pasture in stage 1, and of concentrates and silage in stage 2. Minimum protein requirements are specified for cows in stage 1 and for all types of livestock in stage 2. Sub-matrices for each type of livestock, with a repetition of the feedstuffs in each, are necessary to avoid possibilities for surplus nutrients being passed on from one type of animal to another. One constraint per livestock type ensures that a maximum of 15% of the energy content in the annual feed ration can be of conventional origin (Debio, 2003).

2.3. Specification of stochastic variables

Many of the data requirements for stochastic models are similar to those of deterministic models. However, additional data are needed in stochastic models to represent uncertainty. Outlined here is how we specified the stochastic variables, which were revenue and crop yield variables.

To represent the uncertainty in activity revenues[1], we mainly used the method described in Hardaker et al. (2004a: 80-82). We used historical data from 1993 to 2002 for organic dairy farms in the Norwegian Farm Accountancy Survey to estimate the historical variation in activity revenues per unit within farms between years. The Norwegian Agricultural Economics Research Institute (NILF) collected the data.

In the panel data used, the number of observations for each enterprise varied from 44 to 51 observations. The number of farms was 11. We used the unbalanced panel data to find the parameters that describe the variation in the individual activity revenues per unit within farms between years. For activity *j* we estimated the following two-way fixed effects model:

$$x_{wT} = \mu + \alpha_w + \beta_T + e_{wT} \qquad (2)$$

where x_{wT} is deflated revenue per unit on farm w in year T ($T=1,\ldots,10$), μ is general mean, α_w is the effect on revenue due to farm w, β_T is the effect on revenue due to year T, and the residual e_{wT} is a random variable with mean zero. The estimated individual activity revenue per unit for a representative farm for year T is:

$$\hat{x}_{\cdot T} = \hat{\mu} + \hat{\beta}_T \tag{3}$$

We then removed from the panel data the farm-specific effects caused by different management practices, soil quality etc., $\hat{\alpha}_w$, and unexplained white noise, $\hat{e}_{wT}$. We adjusted for trend by regressing the estimated $\hat{x}_{\cdot T}$ from Eq. (3) against time, T, for each activity. We then added the residuals of this regression for each year to our predicted trend value from the regression for the planning year in order to construct de-trended series (row 4 and 5 in Table 1). To reflect the chance that similar conditions to those in each of the data years will prevail in the planning period, we assigned equal probabilities to the historical years or 'states of nature' 1993 to 2002.

[Table 1 about here]

Both national and international developments imply that Norwegian agricultural policy will change in the future. In that case, historical data are not relevant in our decision model. We therefore elicited from an expert group of agricultural researchers the subjective marginal distributions of the individual activity revenues. From these experts we received judgements of the lowest, highest and most likely values of individual revenue for the next 2-3 years. Then, assuming that the individual subjective revenues per unit were approximately triangularly distributed, we calculated means and standard deviations, as shown in row 7 and 8 of Table 1.

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[1] The dairy activities: Revenues from milk and culled cows minus veterinary, medicine and breeding costs. The calves and bull activities: Revenues from selling livestock minus veterinary and medicine costs.

Finally, the historical revenue series were reconstructed, using the formula (Hardaker et al., 2004a):

$$x(n)_{ij} = E\left(x(s)_j\right) + \left\{x(h)_{ij} - E\left(x(h)_j\right)\right\}\frac{\sigma(s)_j}{\sigma(h)_j} \qquad (4)$$

where $x(n)_{ij}$ is the synthesised revenue for activity *j* in state *i*, $E\left(x(s)_j\right)$ is the subjective mean of the revenue of activity *j*, $x(h)_{ij}$ is the corrected historical revenue of activity *j* in state *i*, $E\left(x(h)_j\right)$ is the mean revenue from the corrected historical data for activity *j*, $\sigma(s)_j$ is the subjective standard deviation of the revenue for activity *j*, and $\sigma(h)_j$ is the standard deviation of the revenue for activity *j* from the corrected historical data. The reconstructed series (the two last rows in Table 1) have the subjectively elicited means and standard deviations while preserving the correlation and other stochastic dependencies embodied in the historical data. The reconstructed revenues used in the model were adjusted according to milk yields for dairy cows and stage of production for calves and bulls.

There may be a stochastic dependency between forage and grain production. If there is a correlation between forage yield per ha and grain yield per ha, this should be reflected in the joint probabilities. In our de-trended[2] historical panel data of organic farms (from the Norwegian Farm Accountancy Survey for the years 1993-2002) we found a significant within farm correlation between forage yield and grain yield of 0.10, implying a weak positive correlation.

We used the same panel data to derive the within farm joint distributions of forage and grain yield. From the data we found the within farm standard deviation for forage yield to be 616 FUm/ha[3]. For each farm we calculated mean forage yield and added/subtracted this standard deviation times 0.5. In this way we received two farm-specific limits and three farm-specific forage

[2] We adjusted for trend by regressing forage yield against time for the whole sample. Then, the regression residual for each observation was added to the predicted forage yield for the planning year 2003. Grain yield was de-trended in the same way. With this approach we assumed an equal trend for every farm in the sample. An alternative approach is to de-trend individually for each farm.

[3] One FUm (feed unit milk) is defined as 6900 kJ of net energy lactation.

yields intervals. The same procedure was performed for grain yields, that had a within farm standard deviation of 654 FUm/ha. In the next step we counted the numbers of data points in each of the nine cells in the state of nature matrix, and found the proportion of the data points of each cell to estimate the within farm joint probability distribution between forage and grain yields (Table 2).

[Table 2 about here]

For observations in the low, normal or high production interval, mean values in each interval (Table 2, last row for grain, and last column for forage) were calculated as overall means plus/minus means of deviations from farm means. With this approach to estimate the joint probabilities we used the information that exists in the panel data and we accounted for the specific empirical distributions. For each type of crop in the model, the relative yield differences between the three states of nature in Table 2 determined yield distributions at the various levels of manure application.

2.4. Matrix structure

The two-stage UEP with recourse for the case farm was formulated as follows:

$$\max E[U] = p_{st} U(z_{2st}, r),\ r \text{ varied}, \tag{5}$$

$$\text{subject to } A_1 x_1 \le b_1, \tag{6}$$

$$B_s x_1 + A_{2s} x_{2s} \le b_{2s}, \quad s = 1,2,...,9, \tag{7}$$

$$C_{1st} x_1 + C_{2st} x_{2st} - I_{2st} z_{2st} = f_{st}, \quad s = 1,2,...,9, \quad t = 1,2,...,10, \tag{8}$$

$$x_1 \ge 0,\ x_{2s} \ge 0, \quad s = 1,2,...,9. \tag{9}$$

where:

$E[U]$ = expected utility;

p_{st} = 1 by $s{\times}t$ vector of joint probabilities of activity revenue per unit outcomes given that crop yield state of nature, s (cf. Table 2) and season state of nature, t (cf. Table 1) has occurred;

$U(z_{2st}, r)$ = $s \times t$ by 1 vector of utilities of net income z_{2st}, where the utility function is defined for a measure of risk aversion, r that is varied in the range $r_L \leq r \leq r_U$;

z_{2st} = $s \times t$ by 1 vector of net income;

A_1 = m_1 by n_1 matrix of technical coefficients in stage 1;

A_{2s} = m_{2s} by n_{2s} matrix of technical coefficients in stage 2 and state s;

x_1 = n_1 by 1 vector of activity levels of first-stage decision variables, representing decisions that must be made before the values of uncertain parameters are observed;

x_{2s} = n_{2s} by 1 vector of activity levels of second-stage decision variables given state s, representing recourse actions that can be taken after a specific realization of the embedded risk parameters is observed;

b_1 = m_1 by 1 vector of resource stocks in stage 1;

b_{2s} = m_{2s} by 1 vector of resource stocks in stage 2 and state s;

B_s = set of s matrices linking first and second stage activities;

C_{1st} = $s \times t$ by n_1 matrix of activity revenues per unit level in stage 1;

C_{2st} = $s \times t$ by n_{2s} matrix of activity revenues per unit level in stage 2;

f_{st} = $s \times t$ by 1 vector of fixed costs;

I_{2st} = set of $s \times t$ by $s \times t$ identity matrices in stage 2.

Eq. (6) represents the immediate first-stage constraints, those that involve only the variables that cannot be delayed. Eq. (7) denotes the second-stage constraints for each state of crop yields. In Eq. (8) activity revenues of first- and second-stage decision variables are linked to the accounting of the final net incomes for each state of crop yields s and season t. The net incomes are transferred into expected utility in the non-linear objective function (Eq. 5).

The matrix developed comprised about 380 activities and 350 constraints. It was solved using GAMS/CONOPT3. Because this software does not include a parametric programming option, solutions were obtained for stepwise variation in r (cf. Eq. 1).

2.5. Stochastic efficiency analysis

Hardaker et al. (1991) proposed that the efficient solution within the range $r_L \le r \le r_U$ of the UEP is identical with the concept of stochastic dominance with respect to a function (Meyer, 1977), or the alternative concept stochastic efficiency with respect to a function (SERF) (Hardaker et al., 2004b). The general rule for SERF analysis is that the efficient set contains only those alternatives that have the highest expected utility (measured as certainty equivalents[4]) for some value of r in the relevant range between r_L and r_U. In a utility-efficient stochastic programming model the efficient frontier is directly obtained. The SERF procedure can, *inter alia*, be used to rank various policy alternatives and farm strategies.

Anderson and Dillon (1992) proposed a classification of degrees of risk aversion, based on the relative risk aversion with respect to wealth $r_r(w)$ in the range 0.5 (hardly risk-averse at all) to about 4 (very risk-averse). If the coefficient of absolute risk aversion with respect to wealth $r_a(w)$ is needed, we can use $r_a(w) = r_r(w)/w$ (Arrow, 1965). In this paper, we do not consider utility and risk aversion in terms of wealth, but in terms of transitory income (i.e., a bad or good result in one year has little or no effect on the probability distribution of income in subsequent years, cf. Friedman (1957)). Since we use a negative exponential utility function in terms of transitory income, z, we need a relationship between $r_r(w)$ and $r_a(z)$. Assuming asset integration, Hardaker et al. (2004a) show that:

$$r_a(z) = r_r(w)/w \tag{10}$$

[4] Certainty equivalent (CE) is defined as the sure sum with the same utility as the expected utility of a risky alternative (Hardaker et al., 2004a).

In other words, we need to divide $r_r(w)$ by *w* to obtain the corresponding value expressed as $r_a(z)$. The typical level of a farmer's wealth, *w*, is assumed to be NOK 1,350,000. Then, a value of $r_a(z)$ in the range 0 (risk-neutral) to 0.000003 (highly risk-averse) corresponds to a $r_r(w)$ in the range 0 to 4. This range was used as the risk aversion bounds in this analysis.

3. Application

3.1. Results under prevailing economic conditions

The model was applied for a case farm that reflects the conditions for a typical organic dairy farm in the lowlands of Southern Norway. The farmer owned 25 ha of land, and an additional 15 ha of land could be rented. The annual milk quota was 100,000 litres.

The main results under prevailing economic conditions are first presented. Table 3 summarizes the main activities in stage 1 for the model at different degrees of risk aversion. One important observation is that degree of risk aversion did not influence the optimal activity choice. The very risk-averse farmer ($r_r(w)\approx 4$) (as well as less risk-averse farmers, not shown in Table 3) chose the same farm plan as a risk-neutral farmer ($r_r(w)=0$). Another striking aspect was the rather small fall of the CE with increasing risk aversion, which may reflect the small variability of prices and production between good and bad years.

[Table 3 about here]

Available own and rented land was fully used. More than 25 ha were allocated to forage crops, the rest to grain (included sward establishment under-sown in barley). Manure applications per hectare were highest in grain and lowest in pastures. The model chose to purchase 485 tonnes of conventional manure, applied in addition to manure from the owned herd.

The milk quota was produced with 19.2 moderate yielding cows. The numbers of young stock were determined by the fixed replacement rate. All male calves were kept over the grazing season.

In stage 2, the optimal plans for risk-averse farmers were identical with those identified for risk-neutral farmers. Table 4 illustrates main features of the tactical decisions at stage 2 for the risk-neutral farmer. Many of the tactical decisions were identical in all of the possible states, the numbers of livestock included. The main adjustment to the various crop yield states in stage 2 was to buy and sell grain and silage, depending on the crop yield outcomes. Available family labour not used in the farm business, was used off-farm. This implies that the modelled marginal value of farm labour at least equals the wage rate off-farm (NOK 100 per hour in the calculations).

[Table 4 about here]

Under the prevailing economic conditions, the main solution determinant was not the farmer's risk aversion, but other factors and constraints in the organic dairy system. These results support some previous studies that show the cost of ignoring risk aversion may be small in short-run decision problems in farming (e.g., Pannell et al., 2000; Lien and Hardaker, 2001).

3.2. Effects of greater farm income variability

Norwegian dairy farmers' incomes have been stable over recent decades, as the numbers in Table 1 illustrate. Agricultural policies are being increasingly deregulated and liberalised. One of several effects may be higher instability of farm-level prices and income. To illustrate farm-level effects of a very high price and income variability, we increased, compared to the present situation, the dairy revenue variability from CV 0.06 to 0.31, and the calf/beef revenue variability from CV 0.05 to 0.31 (cf. Table 1). Farmers' economic consequence of this constructed income instability scenario, compared to the prevailing conditions, is illustrated in Fig. 2 with a CE-graph using SERF-analysis.

[Fig. 2 about here]

The CE-graph shows the expected net income (when coefficient of risk aversion is zero) and CE of net income at different degrees of risk aversion. As expected, since we only changed the variability of activity revenues (and not the expected revenues), compared to the prevailing system, a risk-neutral farmer $(r_r(w)=0)$ perceived the same utility of net income under the two scenarios. However, at greater farm income variability a very risk-averse farmer ($r_r(w)\approx 4$) perceived the CE of net income considerably lower (NOK 238,000) than the risk-neutral one (NOK 252,800). The farmer's degree of risk aversion in the instability scenario also had effects on the optimal farm plan. Land in grain increased from 14.2 to 18.5 ha (partly because grain is relatively less risky than dairy and beef in this scenario), the number of dairy cows were reduced from 19.2 to 16, only 83% of the milk quota was produced, more time was allocated to the risk-free off-farm alternative, and several tactical decisions in stage 2 varied significantly between states.

4. Concluding remarks

The objective of this paper was to present a two-stage stochastic utility efficient programming model with recourse applied to an organic dairy farm, and to illustrate how this model can be used in a stochastic dominance framework to examine farm strategies and policies under various scenarios. The model includes risk aversion in the decision maker's objective function as well as both embedded and non-embedded risk. We assumed a one-year farm plan starting in the springtime. The second-stage decisions allowed us to model a response to the observed crop yields outcome after harvesting in the autumn. One set of second-stage (recourse) variables for each of the nine states of crop yields outcome was defined, involving for example feed purchase decisions for the indoor season.

As an illustration of its many potential applications, the proposed model was used to analyse optimal farm plans for an organic dairy system in Norway. Under prevailing economic conditions we did not find any shifts in resource use with increased risk aversion, and the risk-averse farmer was only marginally worse off (measured in certainty equivalents) than the risk-neutral farmer. Other factors, such as production constraints and institutional constraints in (organic) farming appeared more important for the farm plan than the degree of risk aversion, and with a more detailed representation of the production system more sensitivity in the results could have been disclosed. However, in a situation with greater farm income variability, risk aversion may be of higher importance for the optimal plan as well as for how the farmer perceives the utility of income.

Future work will include more applications. For example, the EU regulation governing organic production required 100% organic feed in organic dairy systems from August 2005 compared with 85% earlier in Norway. The model developed can be used to assess adjustments in resource use and financial impacts on organic dairy herds, enabling farmers to make better-informed decisions under the new regulation.

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Tables and Figures

Table 1
Distribution of activity revenues in NOK per dairy cow and per calf/bull by state of nature

State	1	2	3	4	5	6	7	8	9	10	Mean	St.dev.
Trend and inflation-corrected historical incomes:												
Probability	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10		
Dairy cow	19,822	16,967	16,540	16,834	16,929	16,975	15,350	16,214	17,818	17,328	17,078	1168
Calf/bull	6838	8364	9387	15,309	9918	11,023	8418	6265	9100	9480	9410	2502
Statistics from elicited subjective triangular distributions:												
Dairy cow											15,483	901
Calf/bull											8503	404
Reconstructed incomes:												
Dairy cow	17,501	15,460	15,542	14,822	15,377	15,463	14,059	14,860	16,062	15,680	15,483	901
Calf/bull	8080	8334	8509	9450	8585	8765	8343	7995	8451	8514	8503	404

Table 2
Within farm joint probability distribution for yields, and mean yields for each interval (FUm/ha)

	Grain yield				
Forage yield	Low	Normal	High	Total	Mean yield
Low	0.068	0.182	0.045	0.295	3521
Normal	0.114	0.159	0.114	0.386	3662
High	0.068	0.136	0.114	0.318	3860
Total	0.250	0.477	0.273	1.000	
Mean yield	3117	3280	3499		

Table 3
Summary of optimal farm management activities in stage one

	Coefficient of risk aversion	
$r_a(z)$	0	0.000003
$r_r(w)$	0	≈ 4
Economic results (1000 NOK)		
Expected net income/certainty equivalent (CE)	252.8	252.2
Area payments	168.4	168.4
Land use (ha)		
Own land	25	25
Rented land	15	15
Land for grazing, 10 tonne of manure/ha	9.1	9.1
Land for silage, 20 tonne of manure/ha	16.7	16.7
Land for grain, 30 tonne of manure/ha[a]	14.2	14.2
Purchase of manure (tonne)	485	485
Livestock management		
Dairy cows, 5985 kg milk/cow	19.2	19.2
Heifers	5.8	5.8
Sold female calves	3.8	3.8
Keep male calves	9.6	9.6
Milk supply (1000 litres)	100	100
Concentrates, purchased (tonne feed)	12.2	12.2

[a] Sward establishment under-sown in barley is included (8.6 ha)

Table 4
Summary of optimal farm management activities in stage two for a risk-neutral decision maker

	LL[a]	LN	LH	NL	NN	NH	HL	HN	HH
Grain trade (tonne)[b]	–22.8	–24.0	–27.0	–21.7	–24.0	–27.0	–21.7	–24.0	–27.0
Silage trade (tonne DM)[b, c]	2.2	2.2	2.2	0.0	0.0	0.0	–3.1	–3.1	–3.1
Concentrates (tonne feed)	5.3	4.2	4.2	4.2	4.2	4.2	4.2	4.2	4.2
Keep bulls	9.6	9.6	9.6	9.6	9.6	9.6	9.6	9.6	9.6
Livestock paym. (1000 NOK)	152	152	152	152	152	152	152	152	152
Use of livestock shed (m^2)	197	197	197	197	197	197	197	197	197
Off-farm work (hours)	72	72	72	72	72	72	72	72	72

[a] LL, low forage yield and low grain yield: LN, low forage yield and normal grain yield: LH, low forage yield and high grain yield: … : HH, high forage yield and high grain yield.
[b] A positive sign indicates purchase of fodder, a negative sign sale of fodder.
[c] DM = dry matter.

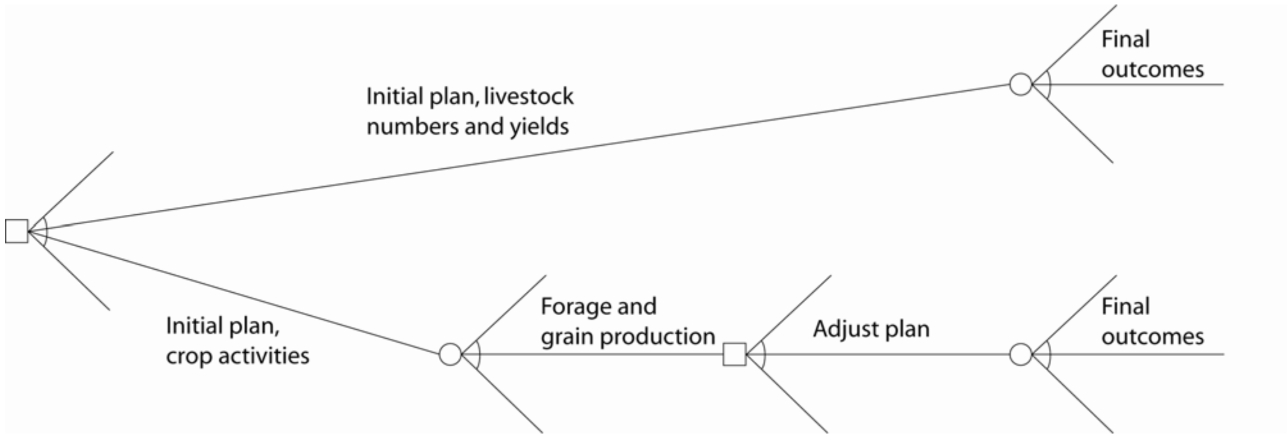

Fig. 1. Outline decision tree for our problem.

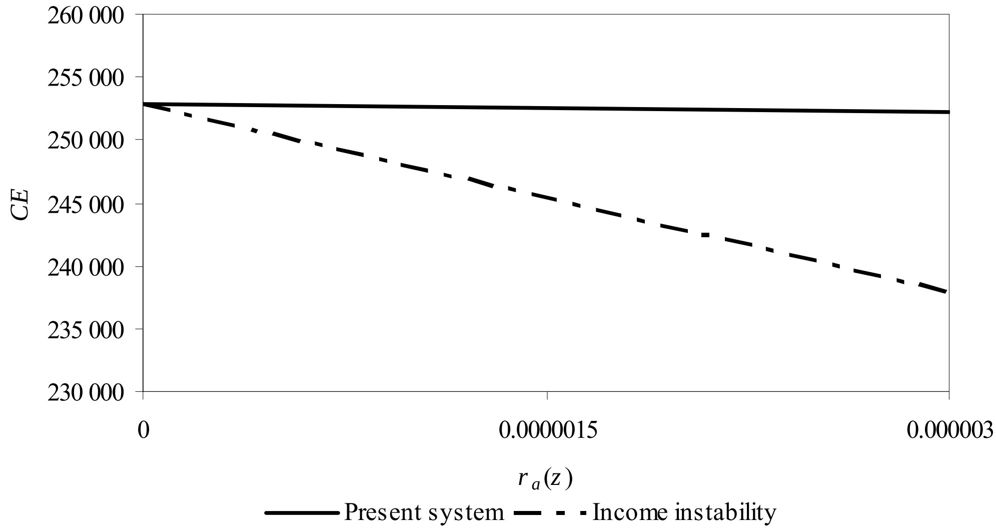

Fig. 2. Certainty equivalents (CEs) under present economic conditions and a constructed income instability scenario. $r_a(z)$ in the range 0 to 0.000003 corresponds approximately to $r_r(w)$ in the range 0 to 4.